TEX4.0

Enabling Industry 4.0 Skills in Textile SMEs

TEX4.0 Report & Curriculum

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PART A - TEX4.0 REPORT

Introduction

The TEX 4.0 project aims to provide VET learners, including the current textile workforce and NEETs with training and upskilling on Textile 4.0-related technologies in order to keep up with the rapid technological advances of the sector and to increase their employability opportunities.

The project objectives are:

- to identify the needs of VET trainers and learners in the field of Industry 4.0 technologies training
- to develop a curriculum on Industry 4.0 skills in the Textile sector for VET Trainers
- to equip VET trainers, learners, and textile stakeholders with the necessary knowledge and tools through an innovative training package on Industry 4.0-related skills
- to provide an e-learning format with attractive and dynamic functions where all material will be integrated
- to implement engaging training activities using participatory approaches in order to test the results and upskill the target groups
- to disseminate the project results through partners and the project's networks and enhance their impact across the EU.

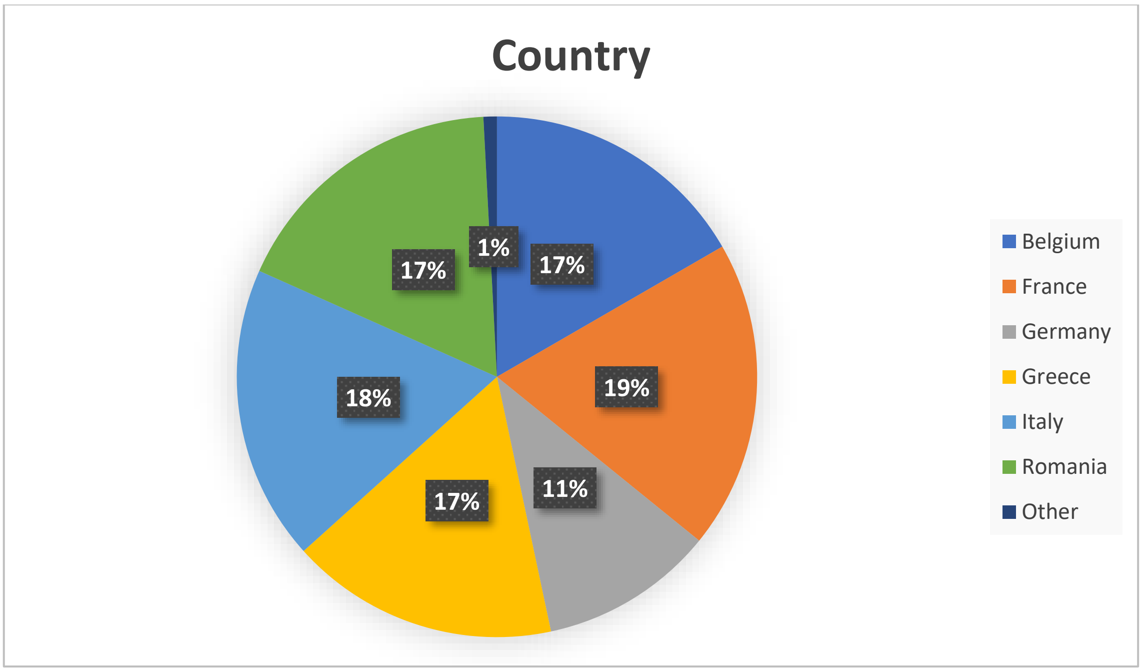
The purpose of this report is to point out existing knowledge, gaps, and educational needs related to Industry 4.0 and its underlying technologies for the textile sector, identified through a wide survey with the participation of VET trainers, VET learners, and textile stakeholders (owners, managers, Chamber of Commerce representatives). The survey outcomes included in the report will lay the ground for the creation of the TEX4.0 Curriculum, which is expected to cover a spectrum of Textile 4.0 technologies and practices to better understand Textile 4.0 and its underlying technologies, what are the gaps and needs, and how the technologies can be exploited within the textile sector.

The research was conducted in 6 European countries (Belgium, France, Germany, Italy, Greece, and Romania), with questionnaires designed for VET trainers and VET learners as well as focus group discussions with textile stakeholders (owners, managers, Chamber of Commerce representatives). The included questions in the interviews and questionnaires were tailor-made for each of the target groups. During its implementation period, which lasted from February to March of 2024, 120 responses from the VET trainers and 128 responses from VET learners to the research questionnaires were collected from the aforementioned European countries, while overall 33 textile stakeholders participated in the national focus group discussions.

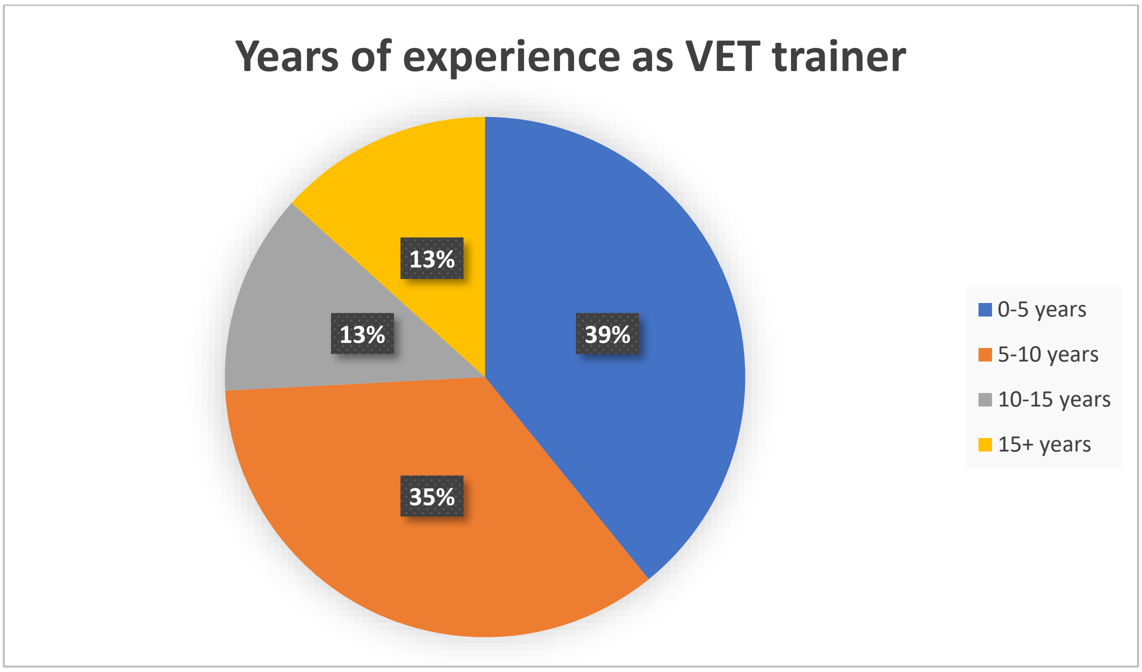
1. National research among VET trainers and learners

1.1 General information

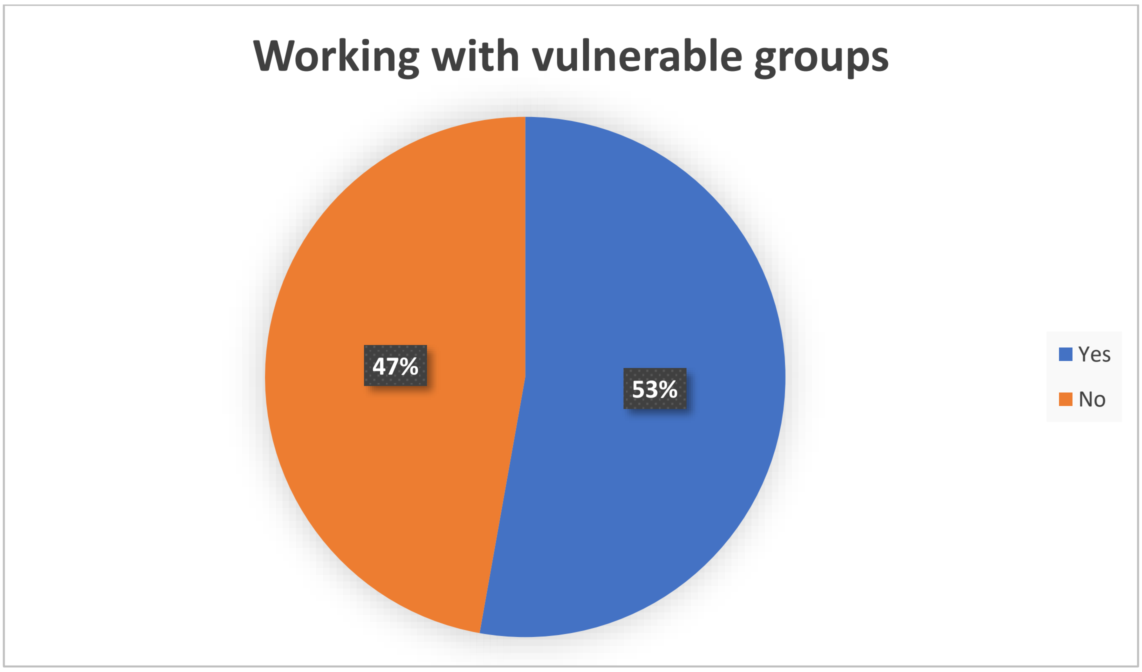
VET Trainers



Regarding the **country of origin** of the VET trainers that participated overall in the surveys conducted at national levels, 19% were from France (23 participants out of 120), 18% from Italy (22), 17% from Romania (21), 17% from Belgium (20) and 17% Greece (20), 11% from Germany (13), and 1% from another country (Ukraine) (1).

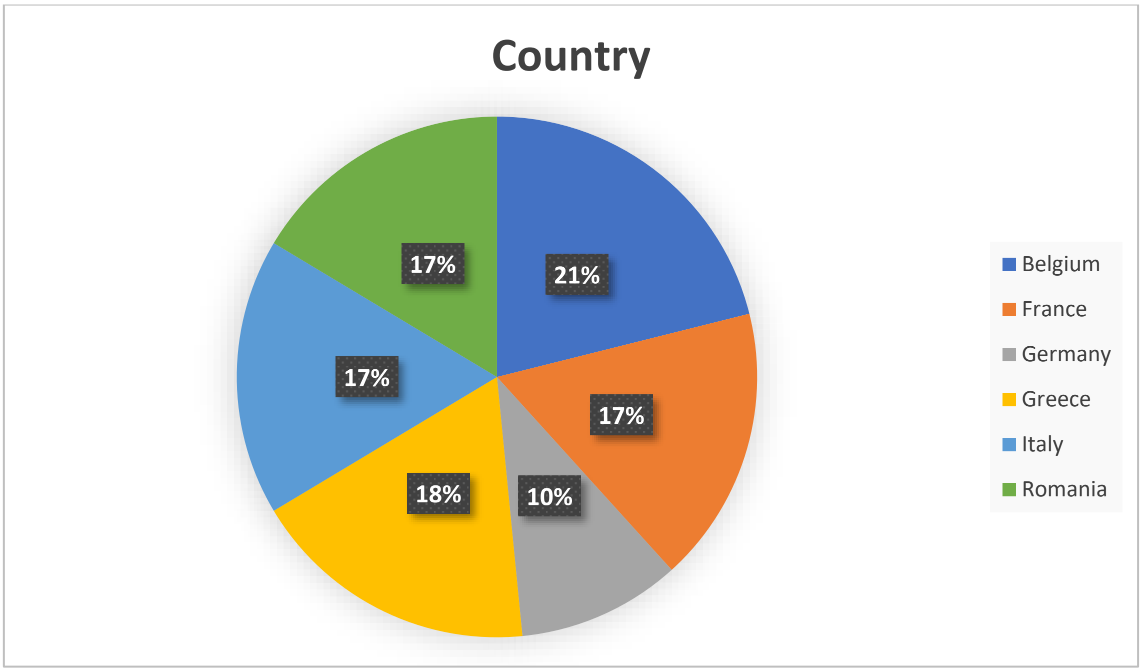


The majority of the survey participants have little to moderate **experience in working in the VET sector** as they have been working from 0 to 5 years (39%) or from 5-10 years (35%) as VET trainers. 13% of them have been working for 10 to 15 years and another 13% for 15+ years in the VET sector, thus being highly experienced VET trainers.

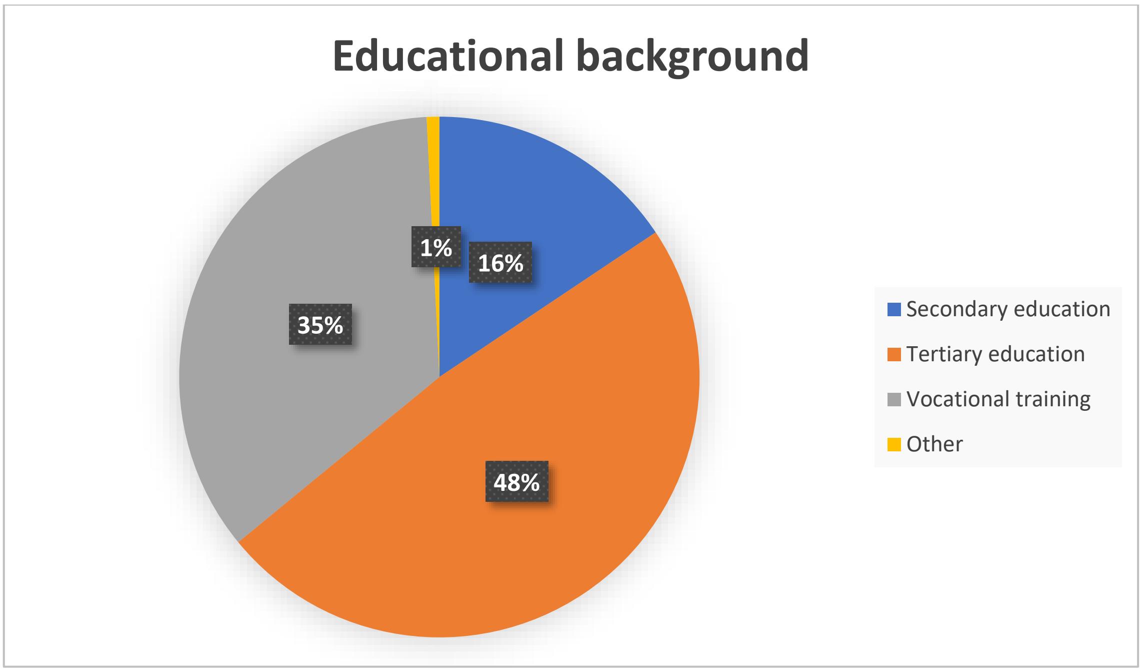


Most of the survey participants (53%) have **worked with vulnerable groups, including NEETs, migrants, refugees, etc.** as VET trainers, while a little fewer (47%) stated that they haven't yet.

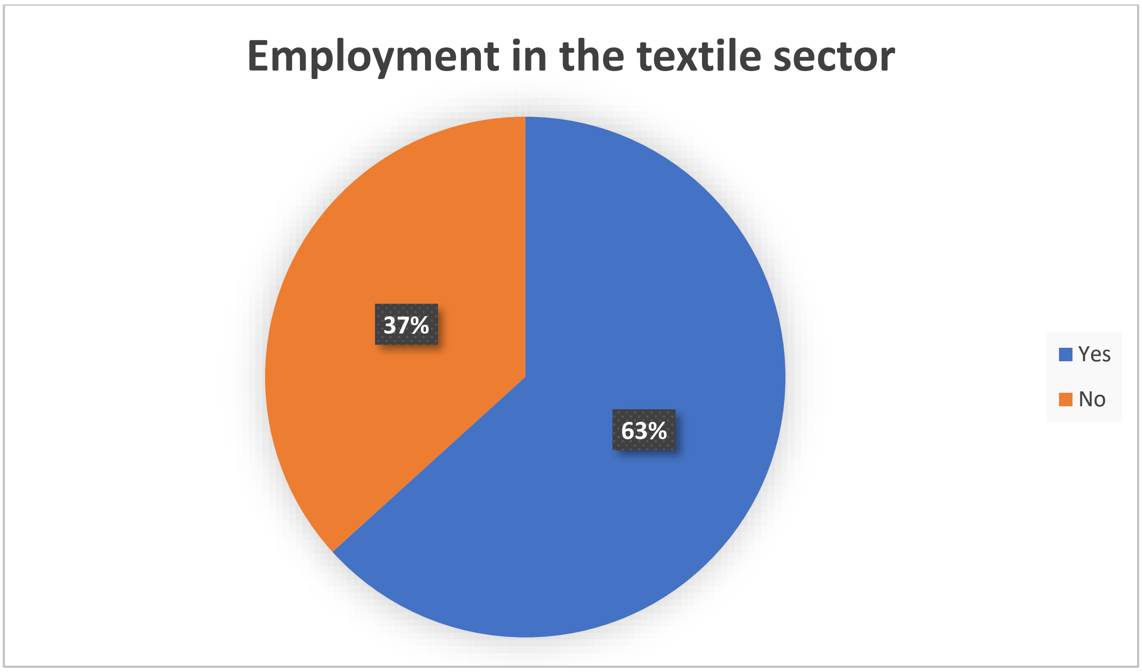
VET Learners



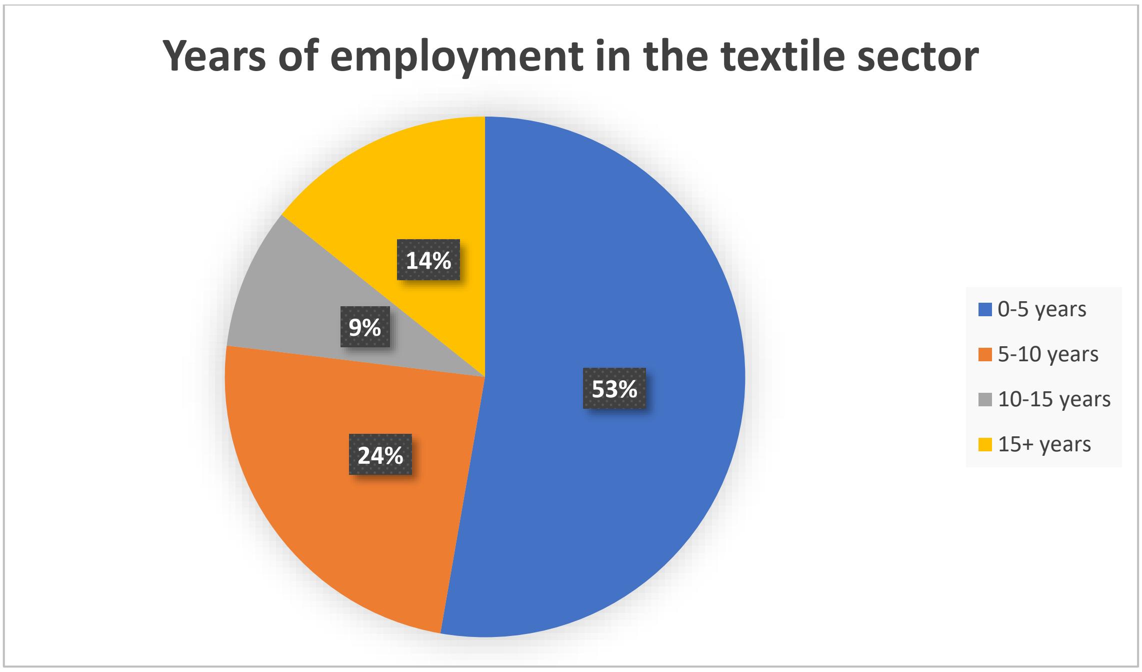
Regarding the **country of origin** of the VET learners that participated overall in the surveys conducted at national levels, 21% were from Belgium (27 participants out of 128), 18% from Greece (23), 17% from Italy (22), 17% from France (22) and 17% from Romania (21), and 10% from Germany (13).



Regarding VET learners' **educational background**, the majority of them (48%) are graduates of tertiary education, while fewer (35%) are VET graduates and graduates of secondary education (16%). One survey participant from Romania indicated that is still a high school ("liceu clasa a 11-a") student.



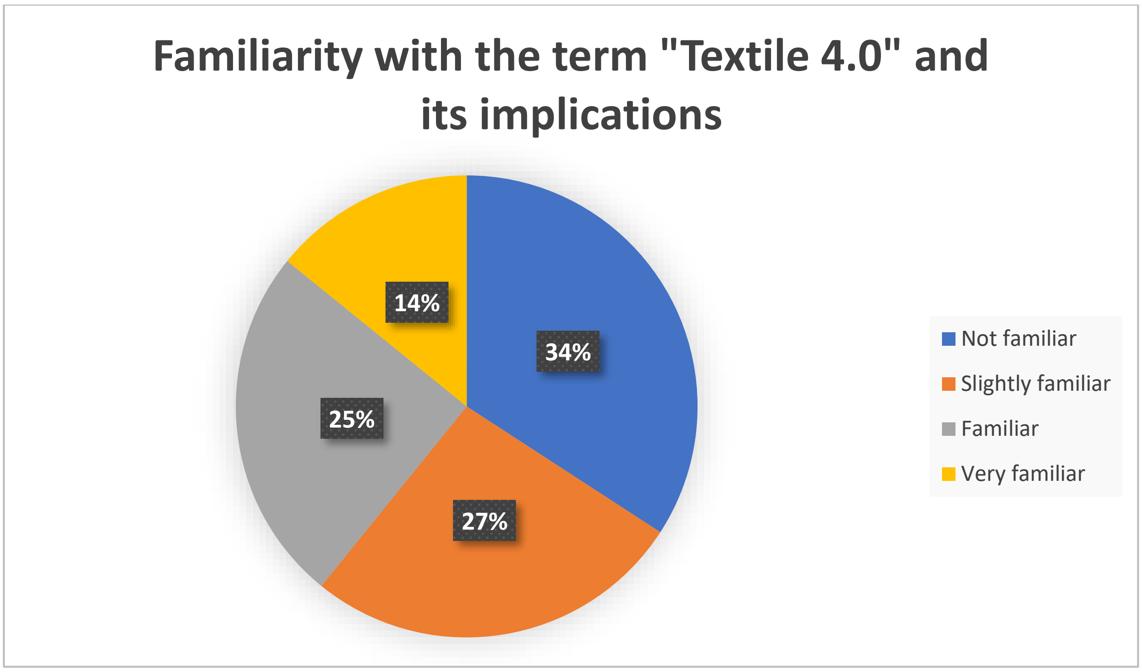
Regarding VET learners' **employment in the textile sector**, the majority (63%) of them are currently employed in the sector's businesses while 37% aren't.



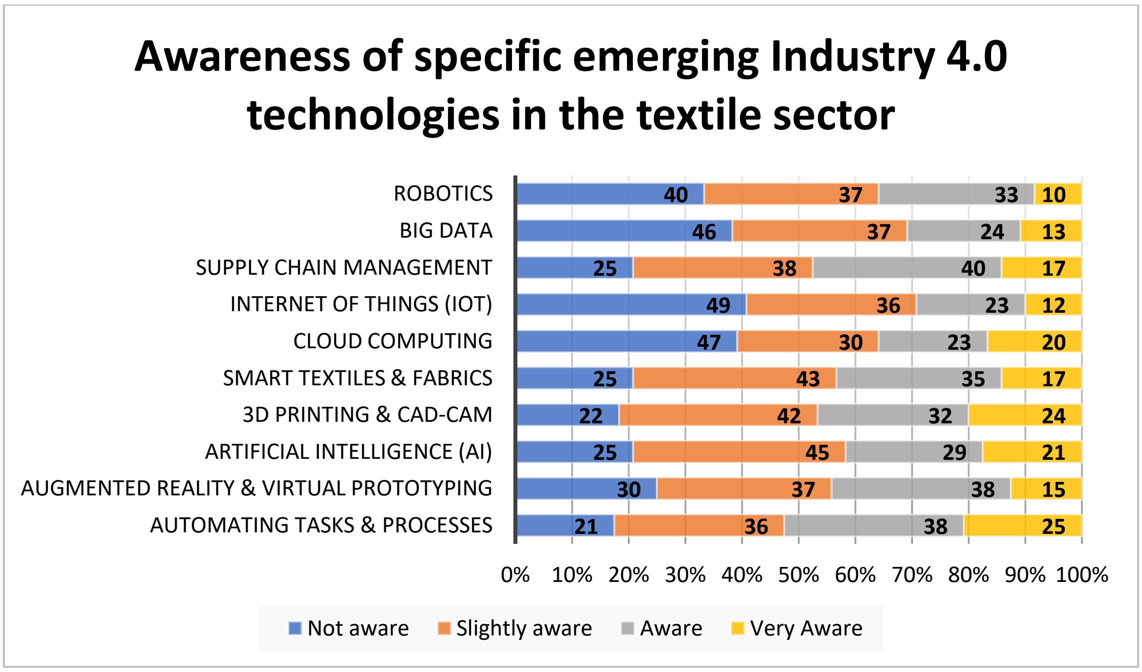
Regarding the **years of employment** of VET learners who are or had been employed **in the textile sector**, the majority (53%) have worked from 0 to 5 years, 24% of them have worked from 5 to 10 years in the sector, while 14% of VET learners 15 or more years of experience in working in textile businesses and, finally, 9% of them have 10-15 years of experience in working in these businesses.

1.2 Awareness of Emerging Industry 4.0 Technologies

VET Trainers

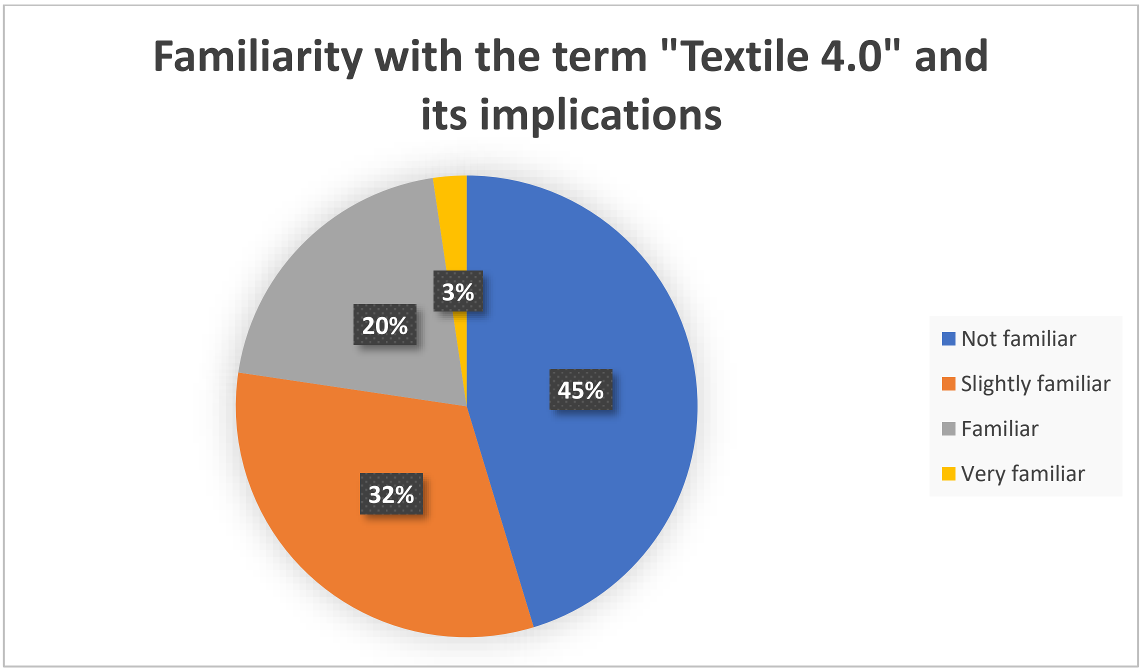


Regarding the **familiarity of VET trainers with the term "Textile 4.0"**, the majority of them seem either unfamiliar (34%) or slightly familiar (27%) with the concept, while 25% of them stated that it is a familiar concept for them and only 14% of them are very familiar with Textile 4.0 and its implications.

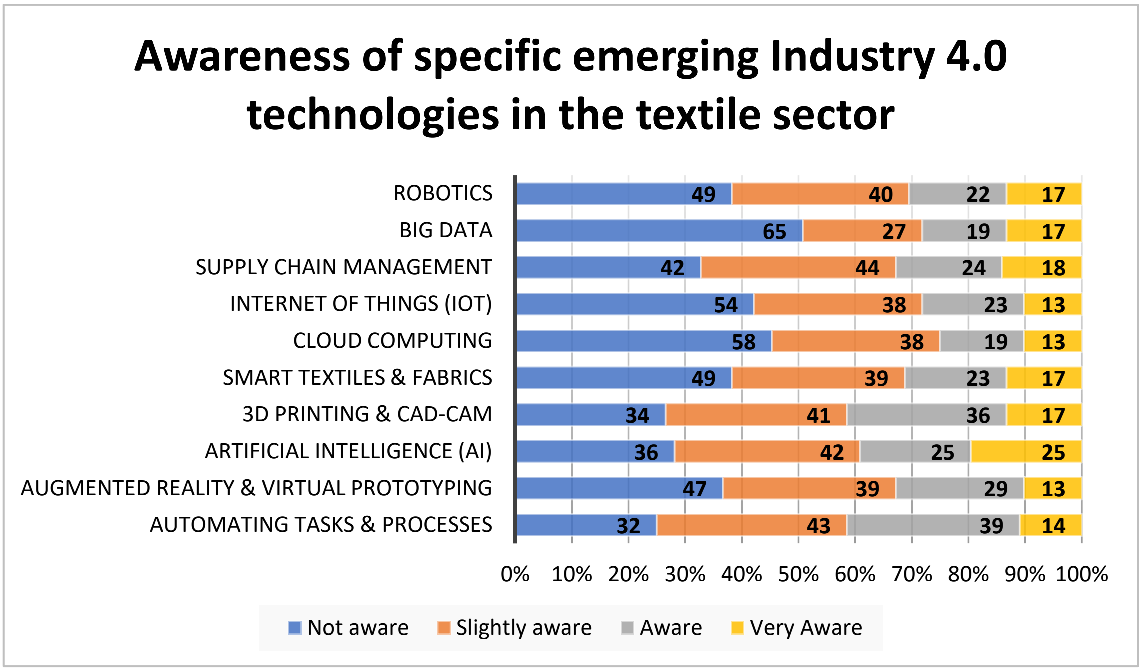


Regarding VET trainers' **awareness of specific emerging Industry 4.0 technologies**, which can be applied in the textile sector, most of them stated they are either slightly or completely unaware of them, ranging from 47.50% (57 responses combined) up to 70.80% (85 responses combined). Overall, they declared themselves as more unaware of "Internet of Things" (70.80% - 85 responses combined) and "Big Data" (69.20% - 17 responses combined), as well as "Cloud computing" and "Robotics" (64.20% - 77 responses combined each). On the other hand, fewer VET trainers declared themselves as aware and very aware of these technologies, ranging from 29.20% (35 responses combined) up to 52.50% (63 responses combined), with the higher percentages of awareness to be found in "Automating tasks & processes" (52.50% - 63 responses combined) and "Supply chain management" (47.50% - 57 response combined), followed by "3D printing & CAD-CAM" (46.70% - 56 responses combined).

VET Learners



Regarding the **familiarity of VET learners with the term "Textile 4.0"**, the majority of them seem either unfamiliar (45%) or slightly familiar (32%) with the concept, while 20% of them stated that it is a familiar concept for them and only 3% of them are very familiar with Textile 4.0 and its implications.



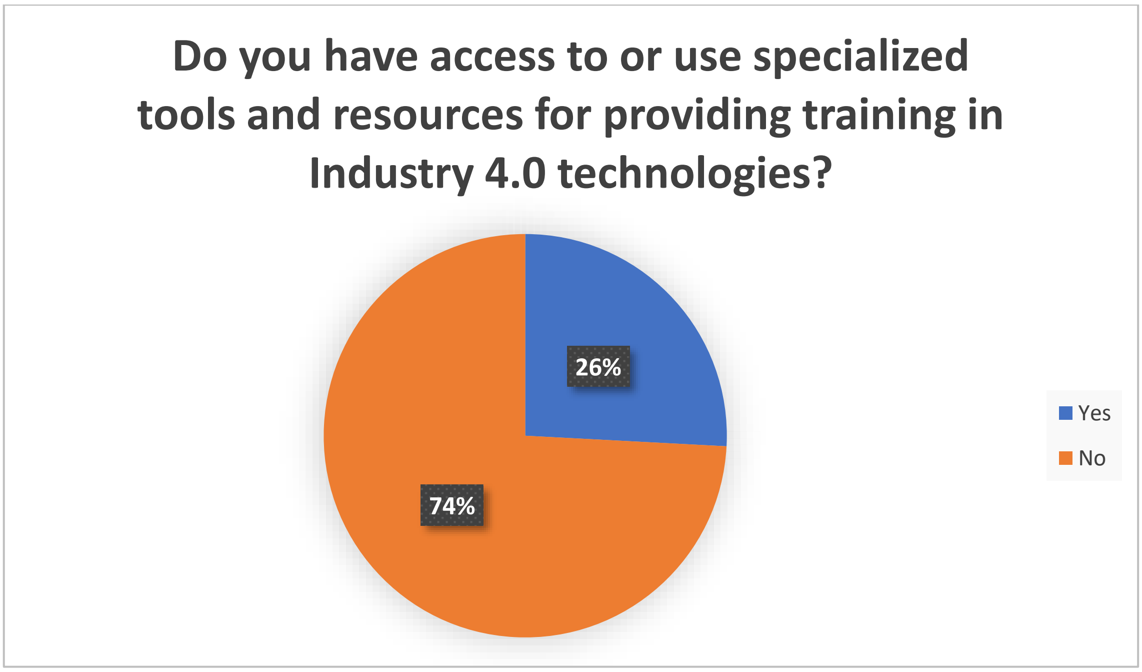
Regarding VET learners' **awareness of specific emerging Industry 4.0 technologies**, which can be applied in the textile sector, most of them stated they are either slightly or completely unaware of them, ranging from 58.60% (75 responses combined) up to 75% (96 responses combined). Overall, they declared themselves as more unaware of "Cloud computing" (75% - 96 responses combined), followed by "Big Data" and "Internet of things" (71.90% - 92 responses combined each). On the other hand, fewer VET learners declared themselves as aware and very aware of these technologies, ranging from 28.10% (36 responses combined) up to 41.40% (53 responses combined), with the higher percentages of awareness to be found in "3D Printing & CAD-CAM" and "Automating tasks & Processes" (41.40% - 53 responses combined each), followed by "Artificial Intelligence" (39.10% - 50 responses combined).

Regarding the open-ended question to VET learners to **provide examples of implications of Industry 4.0 technologies in the textile sector**, it is identified that there are profound ones that include impact creation both by technological advancements and at a societal level. In general, the responses provided indicated that augmented reality and virtual prototyping facilitate training to be efficient as well as contribute to waste reduction, while automation and robotics contribute to accelerating the production processes but this also could often lead to job losses, particularly for textile workforce members with low-skill levels. Additionally, AI and Big Data can help with any process optimization and supply chain transparency, however their complexity and cost of use are perceived as challenges. Furthermore, the integration of IoT could enable remote management of the machinery equipment, thus potentially leading to extended operation schedules and the need for additional working hours for the textile workforce. Despite the advantages of their use, relying on these technologies raises concerns by Vet learners regarding data security, environmental impact, and possible difficulties that older textile employees may face in adapting to their use. Also, even though they acknowledge that these technologies promise more sustainable practices and improved balance between personal and work life, VET learners pointed out a tendency for job displacements due to technological advancements in the textile sector.

Finally, regarding the open-ended question to VET learners to indicate their **awareness of any other Industry 4.0 technologies that can be applied in Textile 4.0 and**, consequently, **their potential implications**, some notable examples mentioned include water treatment for dye reuse, system integration, blockchain, advanced analytics, and online marketing, in addition to some responses indicating technologies already included in the survey. Some specific examples such as Pyratex's natural, biobased fabrics and Tejidos Royo's Dry Indigo technology, which reduces water and chemical usage, were also provided, mentioning that they will be beneficial for the textile sector as they will contribute to increased efficiency, improved production capabilities, and sustainability, despite fears of job displacement and high repair costs that were expressed. Moreover, the Industrial Internet of Things (IIoT) and smart materials were identified as potential game-changers for the sector's future. Finally, many VET learners acknowledged the wide impact of Industry 4.0 on the textile sector, although some of them expressed their unfamiliarity with Textile 4.0 or Industry 4.0 technologies in general.

1.3 Knowledge & Skill Level identification

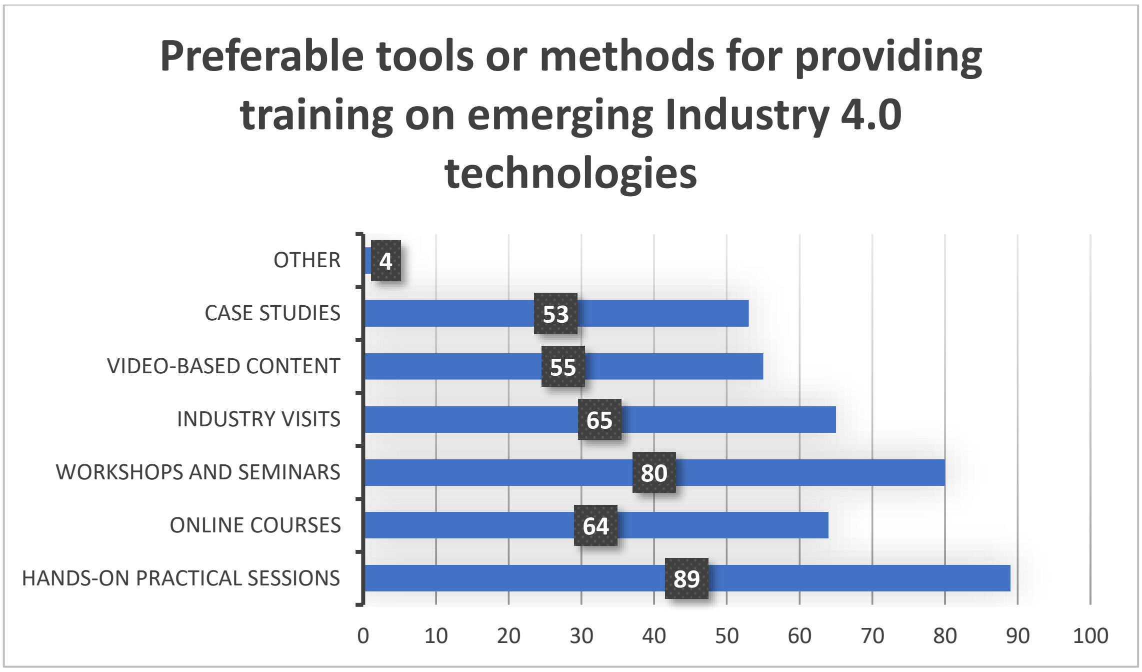
VET Trainers



Regarding the **access to or use of specialized educational tools or resources to provide training on emerging industry 4.0 technologies in the textile sector**, according to the responses provided, the majority of the VET trainers (74%) neither have access to nor use them.

In response to the open-ended question regarding **mentioning the specific tools and resources currently used for providing training related to Industry 4.0 technologies**, the survey participants indicated a diverse range of them that include online courses, videos, and various digital platforms like learning platforms and gamification tools. Also, popular choices were the internet and AI tools such as ChatGPT while developing and accessing distance learning courses tailored for VET trainers and learners was also mentioned.

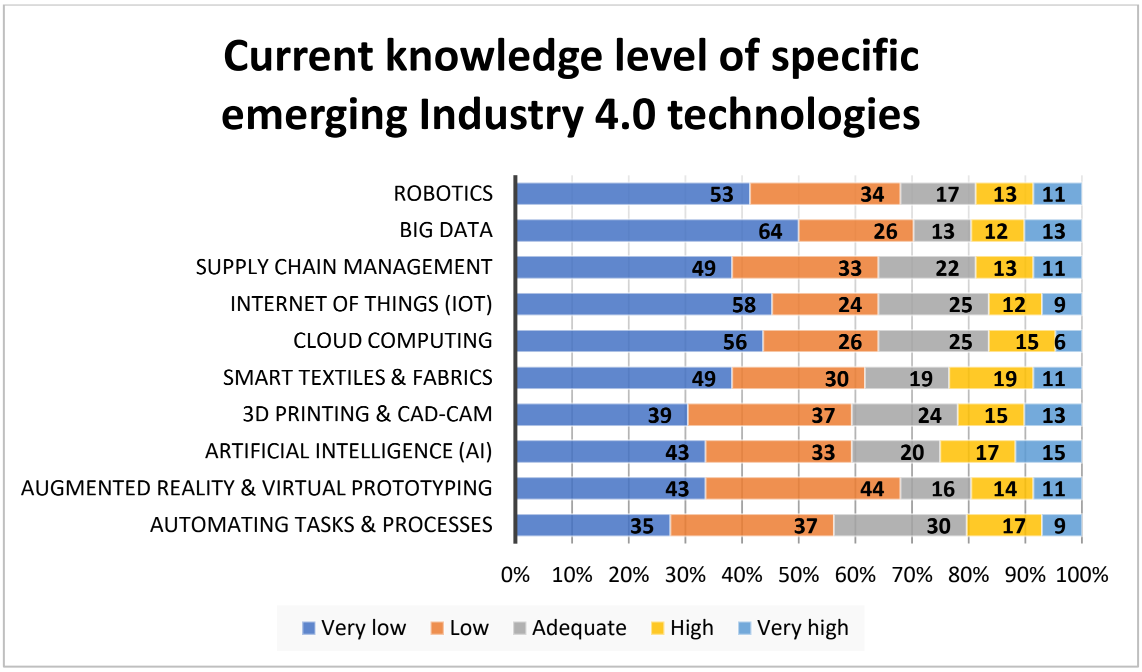
Other notable mentions include the development of a Virtual Reality training program for line operators, along with the digitization of essential skills through short videos and picture dictionaries, as well as specific training programs and systems, such as the Fabricademy in Brussels and the Gemini educational system, and tools such as the "Close The Loop" tool, CLO 3D, the Gerber system, automated sewing machines, cobots, and smart boards is also noted. Presentations, video conferencing platforms, real-time quiz tools, and self-produced content are common methods of instruction. Finally, a keen interest in integrating digital manufacturing within local and circular supply chains was identified.



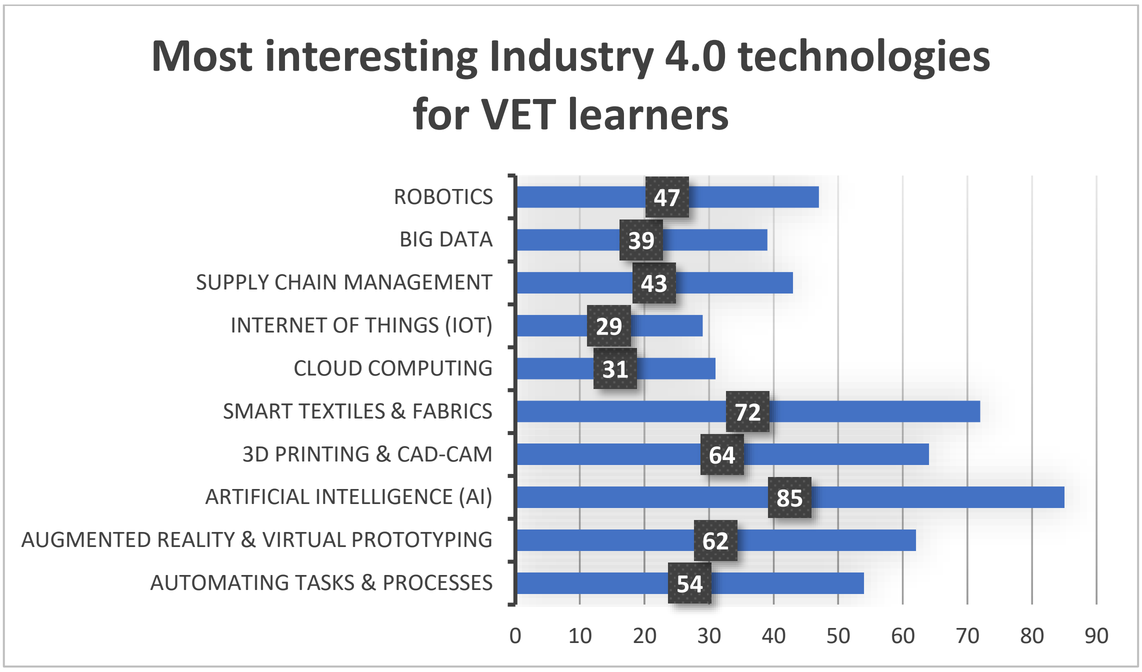
Regarding **tools or methods that VET trainers either currently use or would like to use in order to provide training on emerging industry 4.0 technologies in the textile sector**, the majority of VET trainers (89 out of 120 VET trainers) state their preference for “hands-on practical sessions”, followed by “workshops and seminars” (80 out of 120). On the other hand, the least used or preferable methods are “case studies” (53 out of 120) and “video-based content” (55 out of 120). Finally, regarding the “Other” option, 2 VET trainers stated their preference for “VR training” and 2 others stated that they don’t have any specific preference.

As far as the responses to the open-ended question regarding **if there are any specific topics or skills related to emerging industry 4.0 technologies that VET trainers find challenging to teach**, the responses received from all participating countries indicate in which topics generally VET trainers face difficulties in providing training. So, robotics is mentioned most frequently as a challenge, followed by artificial intelligence (AI), smart textiles and fabrics, the Internet of Things, cloud computing, and automation. Additionally, the general difficulty of learning to use these technologies without adequately equipped training centers and workshops was also pointed out.

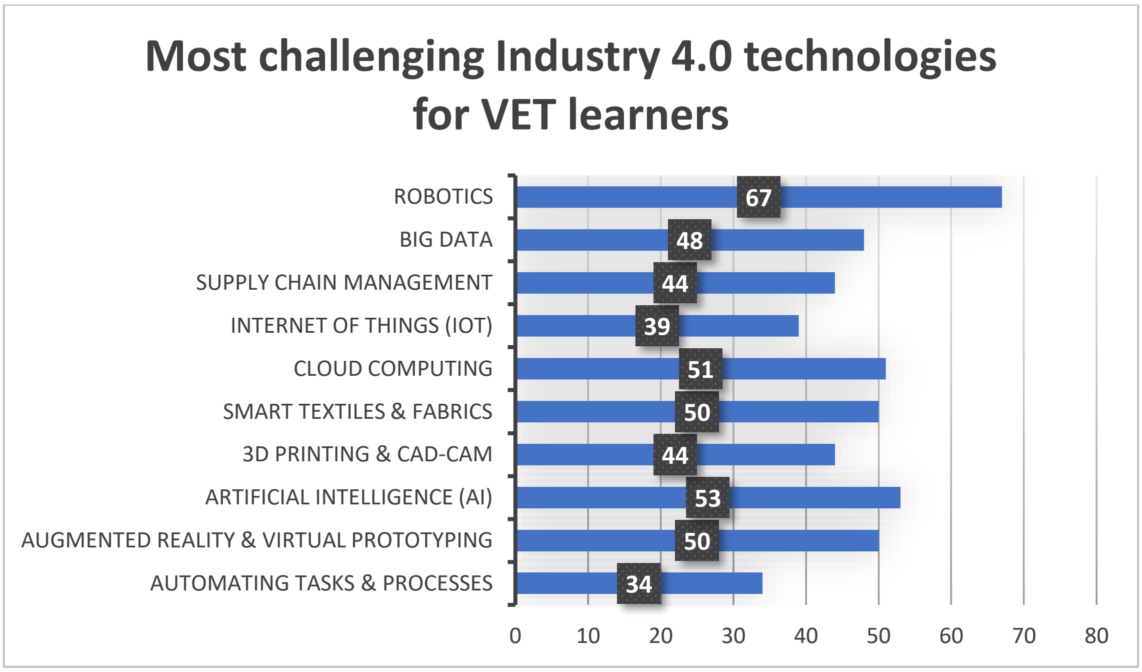
VET Learners



Regarding the **knowledge level of specific emerging Industry 4.0 technologies**, which can be applied in the textile sector, most of the VET learners stated they have either low or very low knowledge of them, ranging from 56.30% (72 responses combined) up to 70.30% (90 responses combined). Overall, they indicated having lower knowledge about “Big data” (70.30% - 90 responses combined), followed by “Robotics” and “Augmented Reality & Virtual Prototyping” (68% - 87 responses combined each). On the other hand, fewer VET learners indicated that they have higher knowledge about these technologies, ranging from 16.40% (21 responses combined) up to 25% (32 responses combined), with the higher percentages of knowledge to be found in “Artificial Intelligence” (25% - 32 responses combined) and “Smart textiles & fabrics” (23.40% - 30 responses combined each), followed by “3D Printing & CAD-CAM” (21.90% - 28 responses combined).



Regarding the **Industry 4.0 technologies** that VET learners consider as **most interesting to learn about**, the majority of them (85 out of 128 VET learners) are more interested in learning about “Artificial Intelligence”, followed by “Smart textiles & fabrics (72 out of 128), “3D Printing & CAD-CAM (64 out of 128), and “Augmented Reality & Virtual Prototyping” (62 out of 128). On the other hand, less interest is shown in learning about “Internet of Things” (29 out of 128) and “Cloud Computing” (31 out of 128).

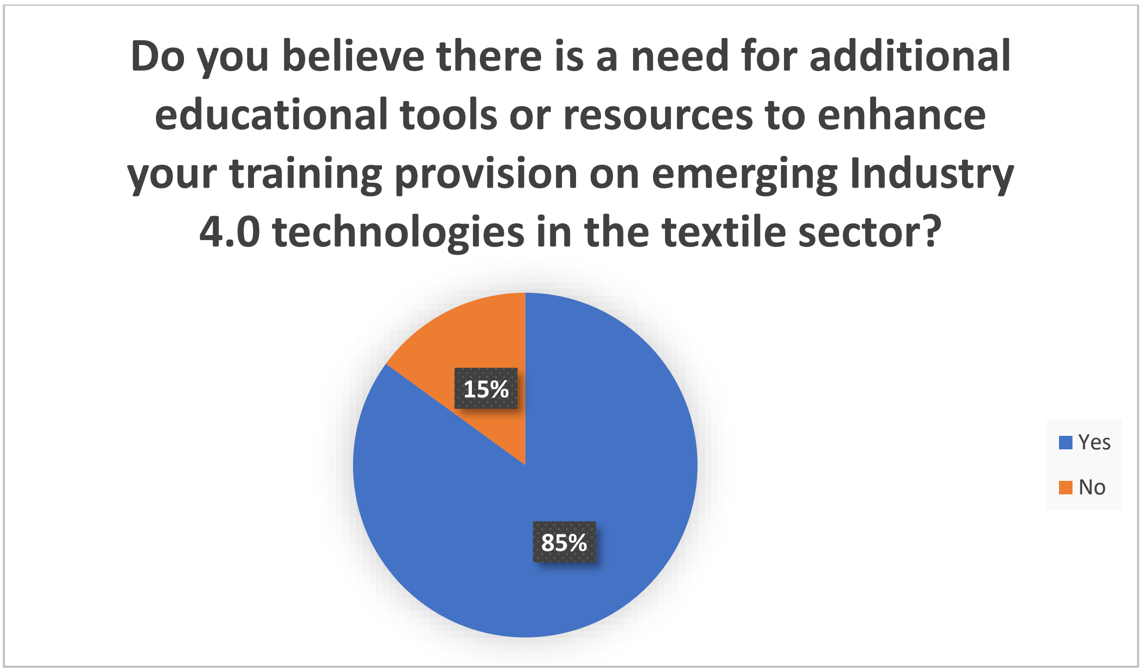


Regarding the **Industry 4.0 technologies** that VET learners consider as **most challenging to use**, the majority of them (67 out of 128 VET learners) find “Robotics” as the most challenging

Industry 4.0 technology in its use, followed by “Artificial intelligence” (53 out of 128) and closely by “Cloud computing” (51 out of 128), “Smart Textiles & Fabrics” and “Augmented reality & Virtual Prototyping” (50 out of 128 each). On the other hand, “Automating tasks & processes” (34 out of 128) and “Internet of Things” (39 out of 128) are perceived as less challenging in their use by VET learners.

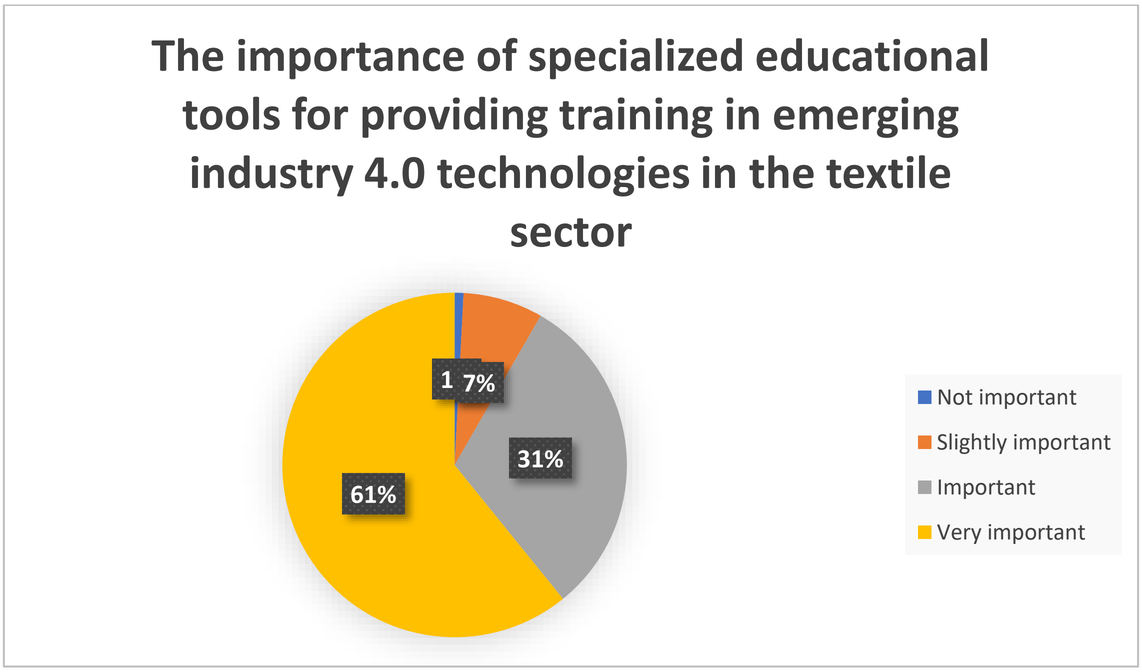
1.4 Educational Needs & Preferences

VET Trainers



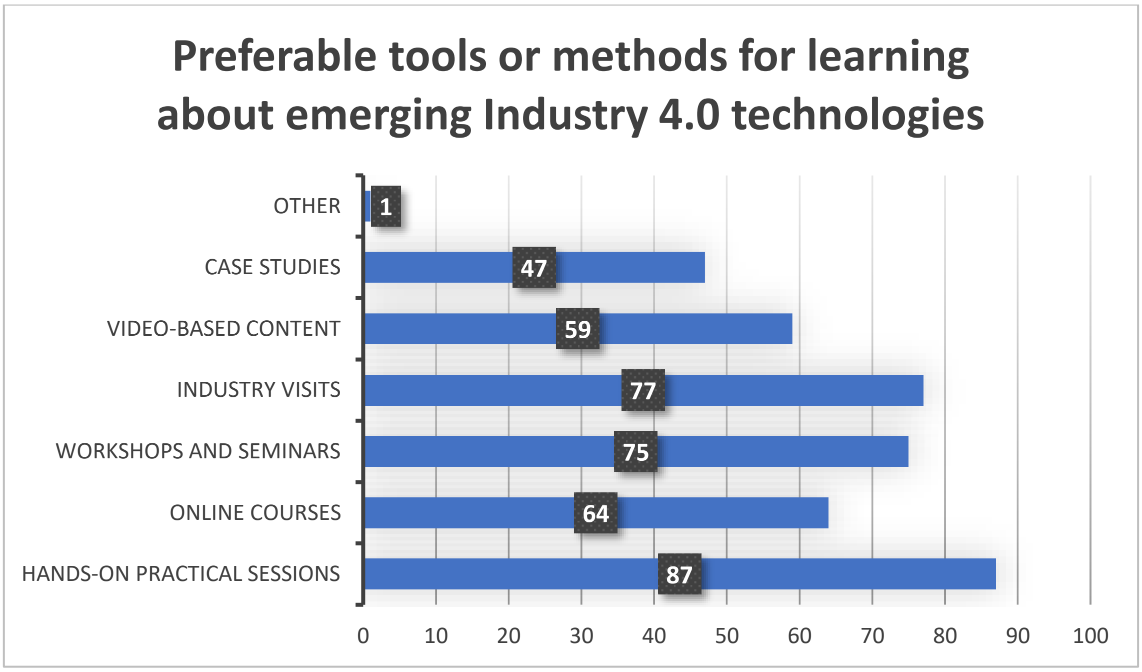
Regarding **the need for providing additional educational tools or resources to enhance training provision on emerging industry 4.0 technologies in the textile sector**, the vast majority of VET trainers (85%) acknowledge it while only 15% of them deny it.

As far as the follow-up open-ended question regarding **specifying any tool or resource types that VET trainers would find most beneficial in this context,** the responses received from all participating countries indicated a mix of digital and practical ones. More specifically, hands-on learning through practical applications, workshops, field trips, and specialized training in a hybrid format was mentioned. As far as the tools and resources indicated, emerging technologies such as artificial intelligence, digitalization, and virtual reality are considered crucial, as well as step-by-step learning materials and specialized software and training equipment. Moreover, accessible and engaging online courses, videos, and tutorials were mentioned as of high importance, along with the ongoing training for trainers. Furthermore, training programs that combine theoretical knowledge with practical applications were perceived as necessary for providing a deeper understanding of Industry 4.0 technologies, as well as the need for support from experts and investments in modern training machinery, especially in regions with limited provision of VET related to textiles.



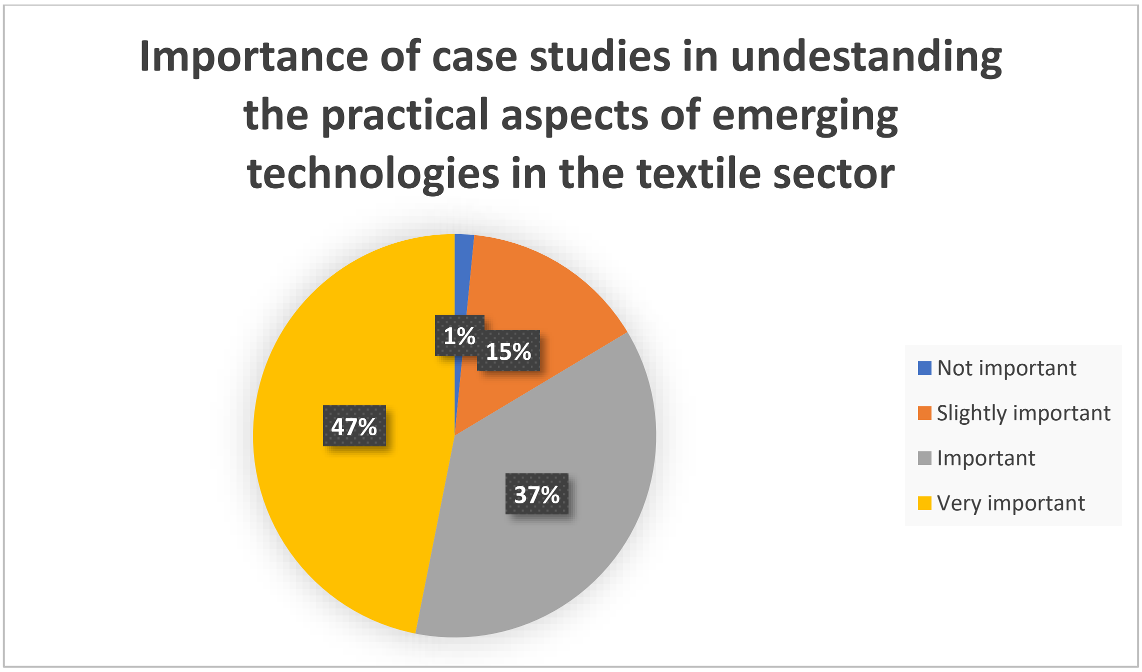
Finally, VET trainers perceive very positively **the importance of having specialized educational tools for providing training in emerging industry 4.0 technologies in the textile sector**, as they rate it as either very important (61%) or important (31%).

VET Learners



Regarding **tools or methods that VET learners prefer for learning about emerging Industry 4.0 technologies in the textile sector**, the majority of them (87 out of 128 VET learners) state their preference for "hands-on practical sessions", followed by "industry visits" (77 out of 128) and "workshops and seminars" (75 out of 128). On the other hand, the least preferable methods are "case studies" (47 out of 128). Finally, regarding the "Other" option, 1 VET learner expressed a preference for "Internet" as a learning tool for these technologies.

As far as the open-ended question regarding **specific topics or skills related to industry 4.0 technologies that VET learners would like to be included in the TEX4.0 curriculum**, most of the respondents expressed their strong interest in Artificial Intelligence (AI) to be included as one of its key components, stressing its importance for various applications. Furthermore, another AI-related perception is its integration with art, design, and fashion which was suggested. Virtual prototyping and process automation were also among VET learners' preferences, showing interest in 3D printing, robotics, smart fabrics and fibers, supply chain management, augmented reality (AR) and virtual reality (VR), as well as cyber security. Additionally, practical applications such as virtual programming and big data were also mentioned. Overall, it is concluded that VET learners expect a comprehensive curriculum that encompasses both theoretical knowledge and practical skills related to Industry 4.0 technologies.

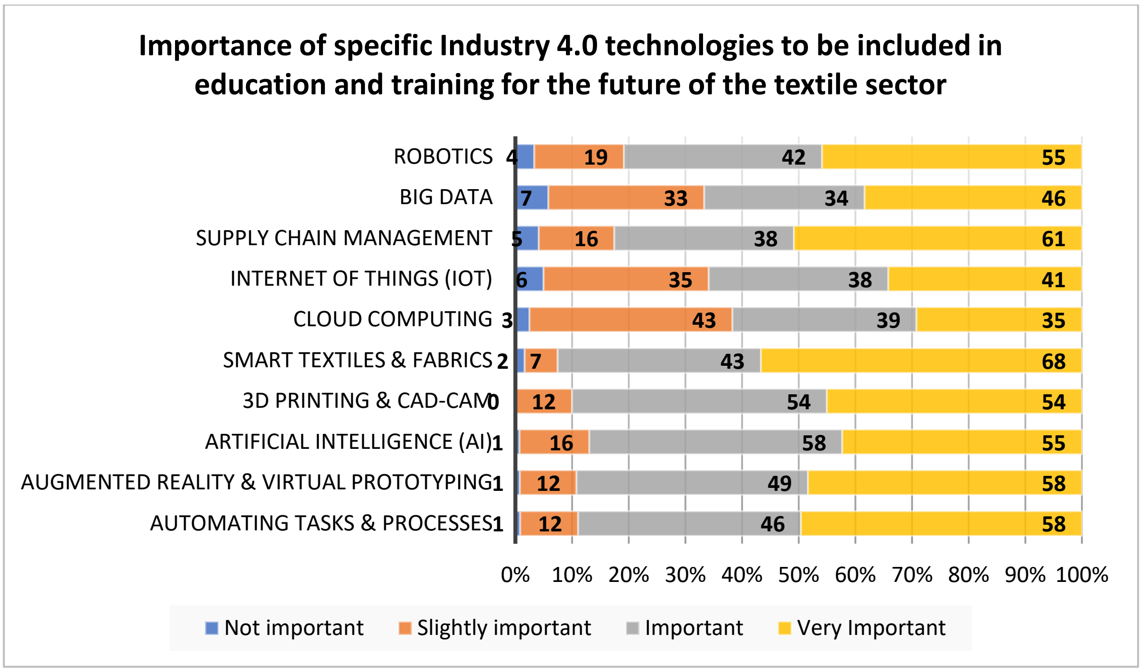


Finally, regarding **the importance of case studies as a means for a better understanding of the practical applications of emerging Industry 4.0 technologies**, the majority of the

VET learners (84%) highly consider them, rating them mainly either as important (37%) or very important (47%).

1.5 Textile Sector Relevance

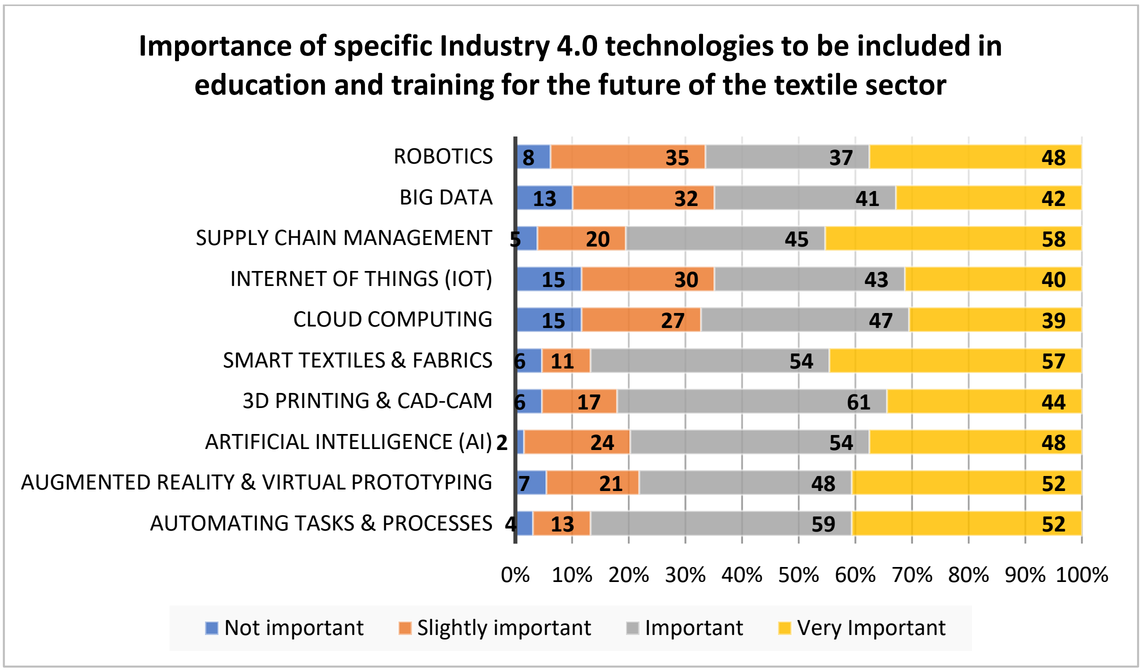
VET Trainers



Regarding VET trainers' perception of **the importance of the emerging Industry 4.0 technologies for the future of the textile sector**, most of them acknowledge their high importance, rating it as either important or very important range from 61.70% (74 responses combined) up to 92.50% (111 responses combined). Overall, based on their responses, the most important of the Industry 4.0 technologies is "Smart textiles and fabrics" (92.50% - 111 responses combined), followed by "3D printing & CAD-CAM" (90% - 108 responses combined), "Augmented Reality & Virtual Prototyping" and "Automated tasks & Processes" (89.20% - 107 responses combined each). On the other hand, the least important industry 4.0 technology for VET trainers seems to be "Cloud computing" as 61.70% of them (74 responses combined) rated it as important or very important, followed by "Internet of Things" (65.80% - 79 responses combined) and "Big Data" (66.70% - 80 responses combined).

As far as the open-ended question regarding **specific challenges or opportunities related to emerging industry 4.0 technologies that VET trainers anticipate for the textile sector in the next decade**, the responses received from all participating countries indicate that generally there are both challenges and opportunities. More specifically, some of the major challenges foreseen are the lack of knowledge and understanding of new technologies among the textile workforce, resistance to change, insufficient training and number of adequately skilled VET trainers, financial constraints, and the rapid pace of the occurrence of advancements in the field of technology. Further challenges mentioned include inadequate infrastructure, the current gap between skills and technological demands, and cultural resistance within textile businesses. On the other hand, among the substantial opportunities mentioned are enhanced productivity, improved sustainability, the potential for the creation of innovative products, more job opportunities, and increased competitiveness.

VET Learners



Regarding VET learners' perception of **the importance of the emerging Industry 4.0 technologies for the future of the textile sector**, most of them acknowledge their high importance, rating it as either important or very important range from 64.80% (83 responses combined) up to 86.70% (111 responses combined). Overall, based on their responses, the most important of the Industry 4.0 technologies are "Automated tasks & Processes" and "Smart textiles and fabrics" (86.70% - 111 responses combined each), followed by "3D printing & CAD-CAM" (82% - 105 responses combined) and "Supply chain management" (80.50% - 103 responses combined). On the other hand, the least important Industry 4.0 technologies for VET trainers seem to be "Big Data" and "Internet of Things" as 64.80% of them (83 responses combined each) rated them as important or very important, followed by "Robotics" (66.40% - 85 responses combined) and "Cloud Computing" (67.20% - 86 responses combined).

As far as the open-ended question regarding **specific challenges or opportunities related to emerging industry 4.0 technologies that VET trainers anticipate for the textile sector in the next decade**, several key perceptions were pointed out. In general, opportunities identified include the integration of AI, IoT, automation, and 3D printing, which will be leveraged to improve operational efficiency, waste reduction, and product customization. These technologies are expected to transform production processes with the use of smart fabrics and towards sustainability. On the other hand, challenges identified include the risk of job loss due to the automation of processes, the lack of skilled workers, the high costs required for the adoption of these new technologies, and general issues related to resource management and sustainability. Furthermore, VET learners expressed several concerns including social acceptance, increased upskilling needs, the balance between technological advancements and traditional practices, financial constraints, and the reluctance or lack of involvement of decision-makers. These factors negatively affect the textile sector's transition efforts towards complying with Industry 4.0.

2. Focus groups' outcomes

The focus group sessions took place as in-person and/or online discussions with a total participation of 33 textile representatives, who were invited to participate and respond to the questions prepared by the TEX4.0 partnership. The profiles of the participants by country include:

Belgium

- 1 CEO of a handmade textile business
- 1 owner of a sportswear and accessories brand
- 1 Director of a national textile training and cluster organization
- 1 Fashion enthusiast with a background in international fashion marketing
- 1 Stylist and modeler student aspiring to start a venture

France

- 8 professionals from the IDL company

Germany

- Dr. Jan Peter Horn, owner and general manager of Herzog GmbH, a global leader in braiding machine manufacturing
- Dipl.-Ing. Herman Güth, CEO of Güth & Wolf GmbH, a major producer of tapes, braids, and belts
- Mr. Niklas Stahleker, CEO of Comazo GmbH + Co. KG, which specializes in functional and protective clothing
- Anke Pfau, head of a department at the Association of Nord-Eastern Germany Textile- and Clothing Industry
- Dr. Axel Spickenheuer, CEO of Complex Fiber Structures GmbH, known for its innovation in CAE design and fiber-reinforced composite parts production

Greece

- 2 production managers from textile companies
- 2 SME owners focused on sportswear and female fashion
- 1 tailor who is also a VET trainer, focused on sewing-related training delivery

Italy

- 1 public official
- 2 entrepreneurs in the textile industry
- 1 university professor and start-up mentor
- 1 manager in a category association

Romania

- 5 VET trainers

The discussions were implemented in participants' national languages; and so were the responses received. The following sections include the conclusions deducted from all the focus group sessions.

2.1 Recent primary technological advancements

The responses received from the participating countries indicate a subtly differentiated landscape of technological advancements that transform the textile sector in them. Despite any differences, several common aspects include a trend towards increased efficiency, sustainability, and digital integration. More specifically:

In **Belgium**, the role of automation and digital machinery across all stages of the textile product life cycle is highlighted while the integration of 3D printing and specialized software facilitates pattern and prototype development with minimal waste reflecting a strong trend towards sustainability. Innovative sustainable fabrics and advanced waste management systems are also considered highly important.

In **France**, automation and robotics for manufacturing, digital textile printing, advanced materials like nanofibers and smart textiles, and the integration of IoT devices for supply chain management and quality control are considered the main technological advancements in the textile sector.

In **Germany**, miniaturization as well as the cost reduction of electronic and mechatronic components are considered pivotal, fostering a deep integration of electronics in textile machines along with the connection between CAD software, CNC controls, and production machinery.

In **Greece**, the importance of automation throughout the textile production process is highlighted, along with the support of 3D printing and artificial intelligence in the design process. Innovations in energy-saving methods and the development of new, high-performance fabrics are also considered crucial while advancements that contribute to the wider sustainability of the textile sector (e.g., new dyeing machines that reduce water usage) are mentioned.

In **Italy**, a dual focus on digitalization and traceability within its textile sector is identified. More specifically, the Prato textile district, which is characterized by small and medium enterprises, has already embraced automation and process digitalization through the use of respective machinery. Additionally, blockchain use for product traceability and certification is highlighted considering the increased demand for transparency and product integrity. Finally, the adoption of 5G technology is mentioned as a support means for optimal communication and data utilization, while challenges related to the integration with larger supply chain players are still present.

In **Romania**, the practical application of technological advancements in education and training is highlighted. The educational focus for the textile sector is on the use of CAD design, digital printing, and automation of production processes, indicating the use of training systems like GEMINI, LECTRA, and Optitex for rapid prototyping as proof of a hands-on approach to embrace technological advancements.

In conclusion, the two most important technological advancements that impact the textile sector are automation and digitalization, which contribute to streamlining the production processes, reduction of manual labor, and, consequently, efficiency enhancement. Additionally, the sustainability aspect stands out due to advancements in waste management, energy-saving technologies, and the development of new, sustainable materials. However, each country seems to have its priorities; namely, in France and Germany, the focus is mainly on advanced materials and integrated electronics, in Italy on digitalization and traceability, while in Romania practical training in cutting-edge technologies stands out. Collectively, these advancements represent a transformative shift towards a more efficient, sustainable, and technologically integrated textile sector internationally.

2.2 Potential gaps or challenges related to emerging Industry 4.0 technologies

The responses received from the participating countries indicate a wide range of challenges faced by the textile sector related to Industry 4.0 technologies. Despite any differences, several common aspects include financial constraints, workforce issues, and systemic barriers. More specifically:

In **Belgium,** there are economic and workforce challenges. A major economic barrier is the need for a substantial investment in the acquisition of digital machinery and advanced technology while a workforce-related barrier is the upskilling need of the current workforce, which lacks younger members, as well as entrepreneurial vision and VET courses dedicated to textiles.

In **France**, significant challenges include the high initial investment costs and the lack of standardized protocols for interoperability. There are also cybersecurity concerns and resistance to change that derive from existing traditional methods, which reflect a broader reluctance to transition to adopt advanced technological systems without concrete frameworks.

In **Germany**, a major challenge identified is the complexity of Human-Machine Interfaces (HMI) due to their lack of user-friendliness and, the requirement of high-qualified staff who, in turn, need extensive relevant training. As a result, this situation hinders the development and maintenance of technologically advanced textile machinery.

In **Greece**, several challenges include the lack of a skilled textile workforce, which has members of old age and face training difficulties. In addition, the training of new textile workforce members is negatively affected by financial constraints, which also affects the acquisition of new machinery. Overall, the sector is underdeveloped, facing frequent business shutdowns rather than growth. While the potential of advanced technologies (e.g., virtual reality) for training is noted, limited investment and capital hinder both their adoption and the sustainability and technological advancement of the sector overall.

In **Italy**, the challenges are related to the integration of processes across different companies within the textile supply chain due to the lack of sufficient collaboration, investment, and communication among the sector's companies complicating any efforts to create a truly integrated process. The Italian textile sector also faces an age gap, as many entrepreneurs and workforce members are getting older while there is a lack of people able to drive its modernization.

In **Romania**, a somewhat different perspective emerged, as no major issues in adopting Industry 4.0 technologies in the textile sector were mentioned. However, a challenge identified is the fear of using new technologies, which is rather a cultural and psychological barrier than financial or structural.

In conclusion, there is a wide range of challenges related to adopting Industry 4.0 technologies in the textile sector across these European countries including the high financial investment requirements, the upskilling need for the aging workforce, and important systemic barriers such as fragmented administrative systems, lack of standardization and interoperability, and insufficient collaboration across the supply chain. The situation is also shaped by cultural resistance to change and psychological barriers. However, targeted investment, training, and collaboration can contribute to gradually addressing these challenges towards a more advanced and efficient textile sector in Europe.

2.3 Current gaps in textile workforce knowledge or skillsets related to Industry 4.0 technologies

The responses received from the participating countries indicate significant gaps in knowledge and skills within the textile workforce, which are required for Industry 4.0 technologies adoption. Some common gaps include the lack of digital literacy, insufficient training, and resistance to new technologies. More specifically:

In **Belgium**, a significant gap in digital literacy among the current workforce is identified, considering that it consists of older individuals (over 40 years old) who often lack the motivation and skills to engage with new technologies. Additional issues include a lack of specialized training provision for both trainers and learners and inadequate financing to integrate new technologies into educational practices.

In **France**, there are gaps in understanding data analytics, IoT integration, cybersecurity measures, and the adaptability related to the adoption of rapidly emerging technologies, indicating a wider need for training that includes various aspects of digital technology and its applications within the textile sector.

In **Germany**, there is a motivation deficiency to learn new skills, especially among the lower-income textile workforce members as well as an overall self-consciousness about new technologies, derived from concerns about their ability to learn and apply them along with their perception that advanced digital skills, such as coding and programming, are beyond their reach.

In **Greece**, there is a serious lack of practical experience and expertise in Industry 4.0 technologies among textile employees, who are unfamiliar with new IT applications, thus hampering the effective use of advanced equipment. Additionally, there is a deficiency of training programs that are updated in line with technological advancements, thus disturbing textile businesses' efforts to hire well-qualified employees.

In **Italy**, the textile sector struggles to attract well-qualified individuals, as only a few of them aspire to join its workforce, while its existing members often face a scientific and technical deficit in their training. Additionally, there is insufficient investment in training for the textile workforce, which is often considered non-essential despite the potential long-term benefits.

In **Romania**, some critical gaps related to the adoption of new technologies include the absence of CAD design in training curricula, a lack of skilled textile employees, and the aging of the respective workforce.

In conclusion, multiple existing knowledge and skillset gaps impede the adoption of Industry 4.0 technologies in the textile sector. To address them, a joint effort of educational institutions, industry stakeholders, and government bodies to develop comprehensive training programs, update educational curricula, and foster a culture of continuous learning and innovation within the sector seem essential to bridge these gaps and enable a smoother transition to advanced Industry 4.0 technologies.

2.4 Importance of training for the textile sector's sustainability

The responses received from the participating countries indicate varying perspectives on the importance of training for the textile workforce, especially regarding augmented reality (AR), virtual prototyping, and smart textiles. Despite any differences, there is a consensus on embracing new technologies to ensure the sustainability and competitiveness of the textile sector. More specifically:

In **Belgium**, training the textile workforce in new technologies is of critical importance to achieve sustainability, which is considered an urgent issue that requires immediate adaptation of work processes and workforce skills. Training is perceived as essential for addressing environmental concerns related to textiles such as high water consumption, pollution, and poor fabric waste management. Finally, it is emphasized that there is a need to develop a new mindset among textile sector stakeholders to further foster its sustainability.

In **France**, the responses were aligned closely with the Belgium ones, as the crucial role of training in advanced technologies is also recognized, while their benefits in design optimization, production efficiency, and product customization are pointed out as essential for the sustainability and the competitive advantage of the textile sector.

In **Germany**, the interest lies in training in smart textiles rather than in AR and VR training, indicating there is a focus on aspects that have the most immediate and significant impact on the textile sector.

In **Greece**, training in new technologies is considered critical, especially as the textile sector in the country is dynamically evolving, for various reasons including the need for skill development to ensure the sector's competitiveness and adaptability to market demands, ensuring textile business viability and compliance with EU targets for emission reduction and water reuse, and achieving standards and certifications that support its sustainability efforts.

In **Italy**, a mixed perspective was received as the importance of training is associated primarily with broader technological advancements that improve order processing, flexibility, product traceability, and practical applications in general, which will help enhance immediate operational efficiency and product authenticity, rather than AR and VR, for example.

In **Romania**, the significant impact of AR/VR technologies and virtual prototyping on the design and production processes is acknowledged, particularly regarding production acceleration and cost reduction, while training in digital technologies is generally considered crucial.

In conclusion, a strong consensus on the importance of training the textile workforce in new technologies to ensure the sector's sustainability and competitiveness is identified. However, in Belgium, France, and Greece the emphasis is on the comprehensive adoption of advanced technologies, while in Germany a more selective approach that prioritizes smart textiles is evident. In Italy, the focus is on practical technological advancements, and in Romania, the significant benefits of AR/VR and virtual prototyping in accelerating production processes are pointed out. Overall, targeted training that addresses both broad and specific technological needs seems essential for fostering the textile sector’s sustainability and competitiveness.

2.5 Barriers to the adoption of industry 4.0 technologies within the textile sector

The responses received from the participating countries indicate a variety of barriers that hinder the widespread adoption of Industry 4.0 technologies within the textile sector, spanning economic, technical, cultural, and infrastructural aspects and reflecting the diverse challenges that each country faces.

In **Belgium**, a key barrier is the lack of skills and availability of trainers able to train the textile workforce on new technologies, which in turn is aging, faces a significant upskilling challenge, and fails to attract young talent so far. Additionally, many traditional textile businesses are reluctant to modernize their operation processes while existing outdated software complicates technological integration. Finally, the lack of funding for training infrastructure and tools is another crucial barrier.

In **France**, costs, including expenses for acquiring and implementing new technologies and upgrading existing infrastructure, are considered a major barrier while the adoption of Industry 4.0 technologies is further hampered by the need for regulatory compliance and a change in mindsets and operational practices.

In **Germany**, there is a profound resistance to learning new technical skills among the existing textile workforce members while machine producers are reluctant to refurbish old operational equipment, preferring to sell new ones, thus constituting a financial and logistical challenge for textile businesses that plan to replace or upgrade their existing machinery.

In **Greece**, economic barriers are predominant, primarily the high costs of purchasing new equipment and training the textile workforce to be able to meet new technological demands. Additionally, there is a lack of investment programs that hinders the textile sector's development, despite the consensus on the necessity of fully exploiting new technologies to justify them, creating a difficult situation for the Greek textile businesses that are also affected by facing competition from countries with lower production costs and dealing with environmental challenges related to waste and energy use from machinery.

In **Italy**, the lack of collaboration along the supply chain, the outdated machinery, and the lack of basic digital infrastructure constitute significant barriers to the adoption of Industry 4.0 technologies, making the textile sector's digitalization process both costly and complex, which is further affected by local crises and geopolitical issues. There is also a cultural barrier, as many textile stakeholders lack an innovation-oriented mindset, being resistant to forward-thinking investments in technology, especially in the sector's fashion segment.

In **Romania**, there is an infrastructure deficit in the educational field, including a lack of proper equipment and specialized software, a deficit of workforce members qualified in the advanced technologies field, and financial constraints that amplify the impact of these barriers on the adoption of Industry 4.0 technologies in the textile sector.

In conclusion, economic barriers, such as the high costs of technology acquisition and training, technical barriers, such as outdated machinery and the lack of necessary infrastructure and software to support new technologies, cultural barriers, such as resistance to change and a lack of innovation mindset, and infrastructural barriers, such as insufficient training facilities and equipment, were identified across the participating countries. Therefore, a holistic approach is required to overcome them, including infrastructure modernization, upskilling training programs development, wider collaboration of textile stakeholders, and fostering a culture of innovation, for the textile sector to embrace Industry 4.0 technologies in its operational practices.

2.6 Importance of investing in relevant training programs

The responses received from the participating countries indicate a collective perspective on the critical importance of investing in training programs that will allow the textile sector to keep up with rapid technological advancements. More specifically:

In **Belgium**, it is highlighted that investing in Textile 4.0 training programs is important for the future development of the sector as there is a significant lack of trainers and specialized training programs. However, this investment constitutes a challenge as the current textile workforce to reluctant to learn new technologies, while there is a shortage of young students interested in being employed in the sector. Furthermore, it is mentioned that for training efficiency reasons any training programs need to be tailored to the specific needs of textile businesses while any technology integration should be user-friendly.

In **France**, investing in training programs is also of high importance to upskill the textile workforce to be able to effectively leverage emerging technologies for the sector and maintain its competitiveness.

In **Germany**, investing in the creation of training programs is supported by the consensus regarding their necessity for adapting the textile sector to any technological advancements.

In **Greece**, there is an imminent need for training textile employees in any technological advancements with the assistance of private initiatives due to the lack of public support. Besides, it is perceived that the sector's competitiveness relies on providing continuous training and specialization in advanced technologies, despite the high cost of implementing training programs, especially for small businesses.

In **Italy**, it is acknowledged that investing in training programs is necessary. However, it is not a current priority for textile entrepreneurs due to their lack of awareness about the importance of the benefits of continuously investing in human capital and integrating training into the business culture, thus their reluctance to provide training to the existing workforce and their preference for hiring already skilled individual instead.

In **Romania**, investing in training programs is equally important, despite the reluctance of economic actors to invest in their development or to provide sponsorships as well as low-income jobs for skilled newcomers in the textile sector that hampers their retention.

In conclusion, investing in training programs is overall acknowledged to contribute to the sustainability and competitiveness of the textile sector amid major technological advancements, despite barriers derived from the economic constraints (high costs, lack of funding, low salaries), skills and skilled trainers' shortages, among others, that need to be overcome collectively. Textile businesses should follow a holistic approach that will help bridge the gap between technological advancements and workforce capabilities in line with their unique needs, thus ensuring a sustainable future for the sector overall.

2.7 Envisionment of an ideal training program to address the industry 4.0 technologies-related needs of the textile sector

The responses received from the participating countries indicate reflect each country's perspective on balancing practical skills with theoretical knowledge, tailored to the context of the textile sector. More specifically:

In **Belgium**, it is perceived that an ideal training program should be user-friendly, combining theoretical knowledge and practical applications, cover the fundamentals of textiles, various fabric types, production cycle, IT skills, and digital marketing, and engage well-skilled trainers with knowledge of both the textile sector and technology advancements.

In **France**, it is perceived that an ideal training program should integrate hands-on experience with theoretical modules, cover the fields of data analytics, IoT, cybersecurity, augmented reality, virtual prototyping, and smart textiles, and provide opportunities for upskilling and continuous learning.

In **Germany**, it is perceived that an ideal training program should be simple, accessible, provide comprehensive information, and overall attractive to learners.

In **Greece**, it is perceived that an ideal training program should balance theoretical and practical knowledge to optimally apply technologies in order to improve efficiency and minimize errors and be in line with the textile sector's needs, with sector-specific research, practical on-the-job training, and continuous updating of trainers on the technological advancements.

In **Italy**, it is perceived that an ideal training program should involve long-term institutional collaboration with the textile sector and provide practical training in Industry 4.0 applications.

In **Romania**, it is perceived that an ideal training program should be practical, be implemented in person, and incorporate all new technologies into the respective training curriculum, focusing on green and circular economy practices in particular. Thus, investments should be attracted during curriculum design and for equipping training providers with relevant machinery.

In conclusion, to ensure comprehensive learning by the textile workforce, an ideal training program should combine theoretical and practical training, focus on key technologies, ensure continuous upskilling opportunities, engage skilled trainers, facilitate institutional collaboration through internships and work-study programs, and incorporate sustainability with a focus on green and circular economy practices. Additional features include adaptability to textile businesses' needs, user-friendliness, and keeping up with technological advancements in the future.

2.8 Existing training challenges or barriers to Industry 4.0 technologies adoption within the textile sector

The responses received from the participating countries indicate that there are significant challenges and barriers concerning workforce education and training regarding adopting Industry 4.0 technologies in the textile sector. More specifically:

In **Belgium,** training barriers identified include a lack of professional training with qualified training staff, a general reluctance to invest in employee training by textile businesses, upskilling and reskilling challenges due to the aging textile workforce, and financial constraints for updating software, machinery, and training tools.

In **France,** training barriers identified include resistance to change by the existing textile workforce members, limited access to training resources, the need for comprehensive reskilling training programs, and inclusivity in technology adoption.

In **Germany,** training barriers identified include the fact that existing training programs lack relevance to and focus on technological advancements, thus their content is characterized by a deficit in application to production and implementation.

In **Greece,** training barriers identified include financial constraints, rigorous cooperation between public and private sectors, the limited number of existing training programs, which are outdated and lack information on the advanced technologies, and training institutions that provide them, shortage of skilled trainers who are also unfamiliar with current technological developments, aging workforce that struggles to adapt to new technologies and lacks basic digital knowledge, and, finally, strict environmental standards.

In **Italy,** training barriers identified include poor funding that leads to time and organizational capacity issues, underestimation of the added value that Industry 4.0 technologies offer by textile entrepreneurs, lack of interest in the textile sector by young people, and the failure to seize opportunities derived from new European regulations.

In **Romania,** training barriers identified include a lack of infrastructure, a lack of sufficient training programs for trainers in the field of textiles, the absence of economic agents in education and training, and shortcomings in the dual education system.

In conclusion, there are common challenges across the participating countries which reveal that adopting Industry 4.0 technologies in the textile sector is hindered by a combination of financial, cultural, and educational barriers such as limited funding for training programs, infrastructure upgrades, and technology acquisition, reluctance to change among older textile entrepreneurs and workforce members, shortage of relevant training programs and qualified trainers, lack of necessary infrastructure and equipment, and limited cooperation between public institutions and private companies.

To address these challenges an approach that includes increased investments in the development of targeted and relevant training programs, fostering a culture of continuous learning and adaptation among textile businesses, and promoting the collaboration between public and private textile stakeholders is required.

2.9 Contribution of collaboration between textile stakeholders, educational institutions, and policymakers contribute to the successful integration of Industry 4.0 technologies into the textile sector

The responses received from the participating countries indicate the successful integration of Industry 4.0 technologies into the textile sector relies on collaboration among textile stakeholders, educational institutions, and policymakers. More specifically:

In **Belgium**, a joint effort among textile stakeholders, educational institutions, and policymakers to integrate Industry 4.0 technologies is highlighted as essential for the upskilling efforts of the textile workforce in order to cope with the market requirements, however, many educational institutions lack funding for comprehensive training provision in advanced technologies while there is a policymaking need for offering hands-on experience to learners, thus fostering a seamless transition of these technologies into the textile workforce.

In **France**, it is perceived that aligning the textile sector's needs with educational curricula, providing funding for training initiatives, and creating supportive regulatory frameworks will be important for integrating Industry 4.0 technologies into the sector's practice.

In **Germany**, it is believed that a "bottom-up" approach should be followed in education and training with a focus on collaboration between institutions and trainers. It is suggested that the focus should be on making technical education, especially for machine operators, more attractive to students and potential workers.

In **Greece**, the need for enhanced cooperation among textile stakeholders, educational institutions, and policymakers is acknowledged to overcome any barriers related to technology adoption. In this context, Greek universities could play a pivotal role in providing training tailored to the textile sector needs, ensuring that curricula and training programs are current and relevant, while it is suggested that an intermediary body could facilitate effective communication and collaboration among textile stakeholders, which will be able to create a comprehensive plan for integrating Industry 4.0 technologies.

In **Italy**, stakeholder collaboration is perceived as crucial for the successful adoption of Industry 4.0 technologies, although it is believed that the local system struggles to support their effective integration, which could be facilitated through an open dialogue with politicians aiming for a policy shift towards the active promotion of these technologies. Additionally, collaboration efforts are hampered by textile entrepreneurs who prefer forming foreign partnerships that are considered more beneficial as well as a lack of trust among stakeholders.

In **Romania**, structured and regulated collaboration at the national level is highly considered but there is a need for a detailed legal framework to support dual education that combines theoretical and practical training. Additionally, there is a call for mandatory, state-subsidized internships, increased wages in the textile sector to attract young people, and structured courses on Industry 4.0 technologies for VET trainers to ensure that they are well-equipped to provide the respective training.

In conclusion, there is a common need for collaboration among textile stakeholders, educational institutions, and policymakers, despite any challenges faced, such as the common issues of inadequate funding and the need for aligning training with the textile sector demands and for fostering a culture of continuous learning and innovation, which could be resolved by this kind of communication and cooperation, thus facilitating the sector’s digitalization, sustainability, and competitiveness.

2.10 Social implications of the 4th industrial revolution's impact on the textile sector

The responses received from the participating countries indicate that there will be various, both positive and negative, social implications of the 4th Industrial Revolution (Industry 4.0) in the textile sector. More specifically:

In **Belgium**, the improvement of employment opportunities for different groups of people and the shift towards more sustainable practices, such as digital prototyping, are perceived as positive social implications of Industry 4.0 on the textile sector while the risk of job displacement in case of training deficit is perceived as negative.

In **France**, increased efficiency, job creation, and improved environmental sustainability are perceived as positive social implications of Industry 4.0 on the textile sector while the job displacement, digital divide, and the ongoing retraining need of the textile workforce are perceived as negative.

In **Germany**, simpler machine processes are perceived as a positive social implication of Industry 4.0 on the textile sector while the struggle of individuals to adapt to new technologies, leading to their exclusion from the sector is perceived as negative.

In **Greece**, increased production, accelerated processes, reduced production costs, and improved wages and working conditions are perceived as positive social implications of Industry 4.0 on the textile sector while potential job losses and the risk of losing traditional crafts and unique products are perceived as negative.

In **Italy**, the country’s textile expertise and robust industrial districts, the improved workforce safety through technologies like blockchain for certification are perceived as positive social implications of Industry 4.0 on the textile sector while the risk of lagging behind other countries in adopting Industry 4.0 technologies due to slower implementation is perceived as negative.

In **Romania**, increased salaries due to higher qualifications, accelerated production, and the creation of unique, intelligent, and environmentally friendly models are perceived as positive social implications of Industry 4.0 on the textile sector while a potential reduction in the number of employees due to automation is received as negative.

In conclusion, Industry 4.0 can provoke a complex interaction of opportunities and challenges that include, on one hand, increased and accelerated production, job creation, improved wages, and working conditions, and enhanced environmental sustainability, and, on the other hand, job displacement, highlighted digital divide, need for extensive textile workforce retraining, and the risk of exclusion of digital illiterate workforce members.

3. Overall research conclusions

3.1 Awareness of emerging Industry 4.0 technologies

There are various levels of familiarity and awareness among VET trainers, VET learners, and textile stakeholders with the concept of "Textile 4.0" and the emerging Industry 4.0 technologies that can be applied to the textile sector.

As far as the VET trainers, a significant knowledge gap regarding the term "Textile 4.0" was identified, indicated by a high percentage (61%) of declared unfamiliarity or slight familiarity with it. There is also a noticeable lack of awareness of VET trainers for Industry 4.0 technologies, being particularly unaware of the Internet of Things (IoT), Big Data, Cloud Computing, and Robotics, among others. Combined with their slightly better awareness of automating tasks and processes as well as supply chain management, a potential focus area for future training programs is indicated.

As far as the VET learners, their familiarity with the "Textile 4.0" concept is even lower compared to that of VET trainers, as 77% of them are either unfamiliar or only slightly familiar with it. Additionally, their awareness of Industry 4.0 technologies is also generally low, being less aware of Cloud Computing, Big Data, and IoT and having higher awareness of 3D printing & CAD-CAM and task automation processes, thus indicating a critical gap in need of being addressed through respective training. Finally, VET learners pointed out potential benefits and challenges of Industry 4.0 technologies, including, for example, the potential of augmented reality in training and in contributing to waste reduction or the fear of job loss due to automation and concerns over cybersecurity and environmental impacts.

Finally, as far as textile stakeholders, they acknowledged the transformative impact of Industry 4.0 technologies on the textile sector, especially regarding automation and digitalization that affect its production efficiency. They also perceive sustainability as of high importance, being driven by energy-saving technologies, waste management improvement, and the creation of sustainable materials. However, different priorities are identified across countries, as in France and Germany the focus is on advanced materials and integrated electronics, in Italy on digitalization and traceability, while in Romania the priority is on practical training in these technologies. Moreover, textile stakeholders are also aware of significant challenges that could hinder the widespread adoption of Industry 4.0 technologies in the textile sector, including the need for investments and upskilling, as well as systemic issues like fragmented administrative systems and lack of standardization. The digital transition of the sector is also complicated by cultural and psychological barriers. Overall, these challenges can be gradually addressed with targeted investments, training, and collaborative efforts of stakeholders.

In conclusion, improved and targeted training in Textile 4.0 and Industry 4.0 technologies seem necessary for the textile sector based on the significant gaps in their understanding and familiarity, identified by VET trainers and learners, in order to allow the textile sector to fully leverage these advancements. The awareness of their benefits and challenges will help design training programs in line with the textile sector's needs, thus allowing the successful integration of advanced technologies in its practices and fostering its sustainable growth.

3.2 Knowledge & skill levels, gaps, and challenges

Several key insights emerged from the survey regarding the knowledge & skill levels, gaps, and challenges among VET trainers, VET learners, and textile stakeholders related to the adoption and use of Industry 4.0 technologies in the textile sector.

A significant gap is identified among VET trainers related to their access to specialized educational tools and resources for teaching these technologies, as 74% of them mentioned neither having access to nor using these resources, despite their available variety, including online courses, digital platforms, and AI tools to virtual reality training programs and advanced systems like the Gerber system and CLO 3D. A strong preference for them towards practical, hands-on sessions and workshops was also pointed out, indicating a need for integrating interactive and experiential learning into future training programs, while case studies and video-based content are less preferred, suggesting they may not be effective or engaging in the context of textile sector. Finally, considerable challenges related to providing training in complex topics such as robotics, AI, and smart textiles, combined with the lack of well-equipped training centers were also mentioned.

A considerable knowledge gap about specific Industry 4.0 technologies is also evident among VET learners, as they rated their knowledge levels from low to very low in technologies such as big data, robotics, and augmented reality. However, a strong learning interest in AI, smart textiles, 3D printing, and virtual prototyping was expressed, indicating a lack of connection between their interests and the current training provision. Finally, robotics, AI, and cloud computing were identified as the most challenging technologies to use, almost similar to what VET trainers mentioned.

In turn, textile sector stakeholders recognize the existence of knowledge and skills gaps that affect the sector's transition to Industry 4.0 technologies. They also pointed out the ability to address them through a coordinated effort across educational institutions, industry actors, and the public sector that will lead to the development of comprehensive training programs, updated curricula with more Industry 4.0-related content, and promoting of a culture of continuous learning and innovation, thus fostering the sector's efficiency and competitiveness.

3.3 Training importance, needs, and challenges

VET trainers and VET learners, as well as textile sector stakeholders, stressed the importance of training for the sector to keep up with technological advancements.

VET trainers acknowledged the need for additional training resources, focusing on the importance of both digital and practical tools, while a hybrid approach that combines theoretical and practical training, including hands-on learning, workshops, industry visits, and specialized training, is suggested. Artificial intelligence (AI), digitalization, and virtual reality (VR) are among the technologies that are pointed out as crucial, along with the development of step-by-step learning materials and a strong demand for engaging online courses, videos, and continuous training for trainers.

VET learners shared a similar enthusiasm for practical learning, generally favoring hands-on practical sessions, industry visits, and workshops or seminars. The importance of case studies as a means to better understand the practical applications of emerging Industry 4.0 technologies was also mentioned, despite being less preferred as a learning method. Additionally, broader AI applications are considered beneficial, along with virtual prototyping, process automation, 3D printing, robotics, smart fabrics, supply chain management, AR/VR, and cyber security. As a result, similar to VET trainers, VET learners seem to seek a curriculum that balances theoretical knowledge with practical applications to ensure that they will be well-equipped to cope with the evolving landscape of the textile sector.

The importance of training the textile workforce in new technologies is also recognized by the textile stakeholders in order to maintain the sector's sustainability and competitiveness, despite the differences among participating countries, as in Belgium, France, and Greece the focus is on the comprehensive adoption of advanced technologies, while in Germany is on smart textiles, in Italy on the practicality of the technological advancements, and in Romania on leveraging AR/VR and virtual prototyping. Additionally, textile stakeholders acknowledged the need for a holistic approach to overcome significant barriers related to the adoption of these technologies, including high costs, outdated machinery, resistance to change, and insufficient training infrastructure.

So, training related to Industry 4.0 technologies in the textile sector requires a well-round approach to allow the sector to cope with the requirements of their integration, including the combination of theoretical and practical training in key technologies, offering continuous upskilling opportunities, engaging skilled trainers, and promoting collaboration between actors from public and private sectors. It is also essential to overcome various barriers at educational, financial, and cultural levels as well as to invest in targeted training programs and updated equipment and also to foster a culture of continuous learning in line with the unique needs of textile businesses to ensure their sustainability and competitiveness in the future.

3.4 Contextualization in the textile sector

The insights from VET trainers, VET learners, and textile stakeholders highlighted the importance of Industry 4.0 technologies for the textile sector, indicating both their significant potential and the challenges their adoption creates.

"Smart textiles and fabrics" is perceived as the most important Industry 4.0 aspect in the context of the textile sector, according to VET trainers, followed by technologies such as "3D printing & CAD-CAM," "Augmented Reality & Virtual Prototyping," and "Automated tasks & Processes", while "Cloud computing," "Internet of Things," and "Big Data" are less considered. Challenges that include a lack of knowledge, resistance to change, and inadequate training of the textile workforce were also mentioned, along with those derived from the lack of funding and the rapid pace of technological advancements. However, several opportunities derived from the adoption of Industry 4.0 technologies are mentioned such as enhanced productivity, improved sustainability, innovative product creation, job creation, and increased competitiveness.

Almost similar to VET trainers, "Automated tasks & Processes" and "Smart textiles and fabrics" are perceived as highly important in the context of the textile sector by VET learners, followed by "3D printing & CAD-CAM" and "Supply chain management", Also, almost similar to VET trainers' perception, "Big Data", "Internet of Things", "Robotics", and "Cloud Computing" are less considered. Additionally, several opportunities derived from the adoption of Industry 4.0 technologies such as AI, IoT, automation, and 3D printing are identified by VET learners for ensuring operational efficiency, waste reduction, and product customization, along with challenges such as potential job losses due to automation, upskilling needs of the textile workforce, high costs, and concerns about resource management and sustainability.

Finally, the need for collaboration among textile stakeholders, educational institutions, and policymakers was stressed by the sector's stakeholders participating in the survey, which will help address the lack of funding and advanced training requirements, while continuous learning and innovation are suggested to be further fostered. It is pointed out that this collaboration will help the sector deal with the complexity of the adoption of Industry 4.0 technologies, which in turn will contribute to accelerated production, job creation, increased wages, improved working conditions, and, finally, enhanced sustainability. However, job displacement, the digital divide, the textile workforce reskilling needs, and the risk of excluding digitally illiterate workforce members are among the major challenges mentioned. Overall, a need for a balanced approach to Industry 4.0 technologies in the context of the textile sector is acknowledged to seize any possible opportunities and address any possible challenges derived from their adoption.

PART B - TEX4.0 CURRICULUM

A. Automating tasks & processes

A1. Objectives

In this course, participants first receive a definition and an overview of the advantages and disadvantages as well as the effects of automation. Furthermore, the procedure, standards and common errors are demonstrated using processes that have already been automated.

A2. Outcomes

A2.1 Knowledge

By the end of this course, learners will be able to:

- know the state of automation in the textile industry, its advantages and disadvantages as well as the effects of automation

- know the methodology, procedure, and common mistakes.

A2.2 Skills

Participants will gain skills to assess the advantages and disadvantages of process automation in the textile industry. Furthermore, they will have learnt the methodology, the approach to automation and how to avoid common mistakes.

A3. Course Outline

1) Introduction to Automation
    a. What is Automation
    b. Benefits and Challenges of Automation in the Textile Industry
2) Automation Technologies
    a. Overview of Automation Tools
    b. Key Components of Automation Systems
3) Case Studies of Successful Automation
4) Planning and Implementing Exemplary Automation Project
5) Programming Basics for Automation

   a. Introduction on Programming Basics
   b. Building Basic Automation Scripts

6) Monitoring and Troubleshooting Automated Processes
7) Future of Automation in the Textile Industry.

B. Augmented Reality & Virtual Prototyping

B1. Objectives

The main objective of this module is to describe the fundamentals of AR technology and development to allow the trainer to understand what AR is, how it can be used in the context of textile industry and what exists in terms of software and hardware. Furthermore, this module will explore the virtual/digital prototyping concepts for the textile industry and provide insights to this technology for textile users.

B2. Outcomes

B2.1 Knowledge

By the end of this course, learners will be able to:

- highlight the differences between augmented reality and virtual reality

- know the main characteristics of AR, the evolution of AR technologies, general hardware components, the best augmented reality software development kits;

- know any software platforms for augmented reality (e.g. Zappar);

- create an account for an AR software platform and use it (e.g. ZapWorks Widgets, a Designer a Studio, etc.)

- create an augmented reality experience using a software platform.

B2.2 Skills

The participants will be able to:

- provide examples of hardware components

- Identify virtual prototyping software and necessary hardware

- Compare augmented reality software

- summarize the principles and characteristics of AR

- summarize the principles and characteristics of virtual/digital prototyping

- provide AR and virtual/digital prototyping examples in the textile industry.

B3. Course Outline

1) The Principles of Augmented Reality (AR)
2) Basic Principles of Augmented Reality
   a. Types of Augmented Reality
   b. Augmented Reality Hardware
   c. Augmented Reality Software
3) Hands-on Practical training in AR Technology
   a. How to start? Create a ZappAR account
   b. Platforms to Create Augmented Reality - ZappAR
   c. Create a ZapWorks Widgets
   d. Create a Designer
   e. Create a Studio
4) AR-based Business Models
   a. Introduction to Business Models
   b. Different Types of Business Models
   c. Case studies of successful use of Augmented Reality
5) Virtual/digital prototyping – introduction, glossary
   a. Specialised software for the textile industry
   b. Virtual/digital prototyping for garments, for the fashion industry.

C. Additive manufacturing (3D Printing)

C1. Objectives

This course aims to provide students with the ability to use additive manufacturing technologies, colloquially known as 3D printing in the textile industry (especially the low-cost processes involved in 3D printing/AM). The course will provide students with an insight into what additive manufacturing is, the different types of methods/technologies and their possible application to the textile industry.

C2. Outcomes

C2.1 Knowledge

By the end of this course, learners will be able to

- understand the basics of AM/3D printing technology and the principles of AM/3D printing processes
- understand the typical workflow for AM/3D printing technology
- know the range of polymers used in AM/3D printing processes
- understand the influence of AM/3D printing process parameters on the prints' performances
- understand the MEX process and know its main process parameters
- know how to operate MEX equipment, monitor it, and provide maintenance
- know how to inspect and post-process MEX parts
- understand the MEX process and know its main process parameters
- understand the VP process and know its main process parameters
- know how to operate VP equipment, monitor it, and provide maintenance
- know how to inspect and post-process VP parts.

C2.2 Skills

The participants will have a basic ability:

- to download, verify, and correct the STL files before usage
- to import the STL file in the slicing software of the AM/3D printing equipment and set the process parameters
- to start and stop the AM/3D printing equipment

- to safely remove the part from the AM/3D printing equipment
- to monitor the AM/3D printing process
- to perform post-processing activities
- to inspect the part (surface quality, defects, dimensional accuracy)
- to perform maintenance tasks based on AM/3D printing equipment documentation.

C3. Course Outline

1) Introduction to 3D printing
   a. Additive Manufacturing approach. 3D Printing technology definition and specific terms
   b. 3D Printing advantages and limitations
   c. Fundamentals of AM technology
   d. AM standardized processes and corresponding feedstock
   e. Typical workflow in AM processes
   f. STL file format use in AM processes
   g. AM applications in different fields of activity
2) Available 3D printing technologies
   a. Type of 3D Printing processes: main characteristics, materials, advantages and limitations, examples
   b. STL file format
3) 3D Printing equipment
   a. RepRap Project
   b. Fused Deposition Modelling /Fused Filament Fabrication process
   c. FDM/FFF equipment
4) 3D Printing an object on a low-cost MEX or DLP printer
   a. Basic parameters for 3D Printing process based on filament deposition (layer thickness, road width, air gap, platform temperature, extruder temperature etc.). Materials issues, especially in terms of their applications for the textile industry

b. Understanding of the influence of building orientation over aspects such as support structure position and volume, surface quality, time and cost, mechanical properties

5) Case studies/applications in the textile industry

a. 3D Printing case studies for the textile industry

b. 3D Printing technology as a support for innovation and creativity. Examples. Success stories

6) Future of 3D printing technologies for the textile industry

a. Myths and reality in 3D Printing
b. 3D Printing risks and regulations
c. 3D Printing trends and developments: new materials, new applications.

D. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM)

D1. Objectives

After the completion of this module, learners are expected:

- To understand the fundamentals of computer-aided technologies in textile processes (design and manufacturing)
- To be aware of the importance of applying CAD/CAM techniques in the garment industry.
- To be familiar with the software tools and design techniques in CAD
- To be familiar with the automation tools and production processes in CAM
- To understand the workflow integration of CAD/CAM

D2. Outcomes

D2.1 Knowledge

By the end of this course, learners will be able to

- understand the fundamentals of CAD/CAM in textile processes
- understand the application of CAD techniques to design processes
- understand the application of CAM techniques to manufacturing processes
- familiarize themselves with software and automation tools used in CAD/CAM.

D2.2 Skills

By the end of the course, learners should be able to integrate CAD/CAM technologies into the textile design and manufacturing process, enhancing both creativity and efficiency in the production of textile products.

- Design creation using CAD software
- Digital pattern drafting
- Basic understanding of CAM software, machine operation, and material handling
- Fabric simulation and virtual prototyping
- Textile and fashion industry standards
- Sustainability in Textiles.

D3. Course Outline

1) Introduction to CAD/CAM in textiles
   a. Concept of CAD/CAM
   b. Importance of CAD/CAM in the textile industry and processes. Advantages.
2) Fundamentals of CAD in textile design
   a. Digital vs traditional design
   b. CAD software overview: Adobe Illustrator, CorelDRAW, CLO 3D, Optitex
   c. Creating digital textile designs: Techniques for creating digital textile patterns and prints; Color management and fabric simulation
3) Fundamentals of CAM in textile manufacturing
   a. CAM software overview: Lectra, Gerber Technology
   b. Automation in textile manufacturing: automated cutting, sewing, and embroidery
4) Integration of CAD and CAM in textiles
   a. Workflow integration: How CAD designs are translated into CAM processes for manufacturing
   b. Integration of CAM in production workflows
5) Future trends in CAD/CAM
   a. The role of CAD/CAM in promoting sustainable textile design and production.

E. Robotics

E1. Objectives

This course is designed to teach the fundamental concepts and tools of general robotics. This is set to include a brief outline of the history and historical landmarks in the development of robotics, different robots, and their operating mechanism.

Further, an overview of the application of robotics in the textile industry, methods of implementation and use and future fields of application will be provided.

E2. Outcomes

E2.1 Knowledge

By the end of this course, learners will be able to

- gain fundamental knowledge of the different robots, operating mechanisms and applications of robotics in the textile industry
- have a broad understanding of which processes have already been robotized and the advantages and disadvantages of this, as well as which processes have the potential to be robotized in the future.

E2.2 Skills

Participants will have learnt how to handle robots safely and competently and how to deal with malfunctions and faults accordingly. Furthermore, they will be able to assess whether the robotization of a process is advantageous and to develop a methodology for this.

E3. Course Outline

1) Introduction
    a) What is Robotics
    b) Brief History of Robotics
    c) Types of Robots
2) Challenges in the Textile Industry
3) Robotics Application in Textiles
    a) Automation in Spinning and Weaving

    b) Robotics in Dyeing and Finishing
    c) Quality Control and Inspection
4) Designing a Robotics System for Textiles
    a) Fundamentals of Robotics Process Design
    b) Programming Basics of Robotics
    c) Exemplary Prototype Development
5) Impact and Future Trends
    a) Economic and Environmental Impacts
    b) Future Trends in Robotics and Textiles.

F. Internet of Things (IoT)

F1. Objectives

After the completion of this module, learners are expected:

- To understand the fundamentals of IoT applied to the textile industry
- To be aware of the importance of applying IoT techniques in the garment industry
- To be familiar with the Smart Textile System and its components
- To be familiar with the application of IoT to manufacturing processes and supply chain management

F2. Outcomes

F2.1 Knowledge

By the end of this course, learners will be able to

- understand the fundamentals of IoT
- understand the application of IoT in the textile process
- understand the importance of IoT in the textile industry
- understand the opportunities and challenges in the sector.

F2.2 Skills

By the end of the course, learners should be able to understand the integration of IoT in the textile manufacturing process and supply chain management.

- Main materials and technologies
- Smart Textile System components
- Data analytics.

F3. Course Outline

1) Introduction to IoT and basic concepts
2) IoT in the textile industry – Internet of Smart Clothing
3) Smart textiles and wearable technology. Materials and technologies.
4) Smart Textile System Components: sensors, actuators, connectivity, etc.
5) IoT in the textile manufacturing process

6) IoT and the supply chain management: Real-time tracking of materials and products; Inventory | Quality control

7) The future of IoT in the textile Industry: opportunities and challenges.

G. Smart Textile & Fabrics

G1. Objectives

This course aims to explore the rapidly evolving field of smart textiles and fabrics, with a focus on basic elements; namely, the concept itself, their types, design principles and their practical applications.

This course is designed to help learners:

- understand the core definition and significance of smart textiles and fabrics,
- explore the various types of smart textiles based on their features and capabilities,
- become familiar with basic design using smart textiles and fabrics,
- examine the practical use and applications of smart textiles
- be informed about the future trends related to the use of smart textiles and fabrics.

G2. Outcomes

G2.1Knowledge

By the end of the course, learners will be able to

- comprehend the essence and the significance of the concept of "smart textiles and fabrics",

- acquire knowledge of the various types of smart textiles, along with their features, capabilities, and functionality,

- familiarize themselves with design principles to be applied in smart textiles' use,

- understand the practical use of smart textiles,

- be aware of future trends and innovations related to smart textiles and fabrics.

G2.2 Skills

The learners will have a basic understanding of their

- ability to adequately explain the concept and significance of smart textiles,

- capability to identify the various smart textile types based on their features and capabilities,

- competence in applying basic design principles for product development using smart textiles,

- acknowledgment of the practical value of smart textiles through their various applications,

- readiness to deal with future trends and innovations related to smart textiles and fabrics.

G3. Course Outline

1) Introduction
2) Overview of smart textiles & fabrics
3) Classification of smart textiles & fabrics
4) Key design principles with smart textiles & fabrics
5) Practical applications of smart textiles & fabrics
6) The future of smart textiles & fabrics
7) Conclusion
8) References

H. Social Implications of Textile 4.0

H1. Objectives

This course aims to provide a better understanding of Textile 4.0 and knowledge about its wider impact on the aspects of employment, economy, environment, as well as of ethics that, in turn, impact on society.

This course is designed to help learners:

- understand more comprehensively the concept of Textile 4.0,
- be prepared for the impact of Textile 4.0 on employment,
- assess the economic impact of Textile 4.0,
- be aware of the environmental consequences of Textile 4.0,
- familiarize themselves with the ethical implications of Textile 4.0.

H2. Outcomes

H2.1 Knowledge

By the end of this course, learners will be able to

- comprehend of the concept of Textile 4.0,

- be aware of the impact of Textile 4.0 on job creation and displacement,

- familiarize themselves with the economic implications of Textile 4.0,

- understand the environmental consequences of Textile 4.0,

- acquire knowledge of the ethical implications of Textile 4.0.

H2.2 Skills

The participants will have a basic understanding of their

- ability to provide insightful explanations of the concept of Textile 4.0,

- preparedness for coping with the impact of Textile 4.0 on employment dynamics within the textile sector,

- well-preparedness to anticipate the economic impacts of Textile 4.0,

- competence in identifying and analyzing the environmental consequences of Textile 4.0,

- optimal ethical consideration of the adoption of Textile 4.0 technologies.

H3. Course Outline

1) Introduction to Textile 4.0
2) Impact on employment
3) Economic impact
4) Environmental impact
5) Ethics of Textile 4.0
6) Conclusion
7) References

I. Artificial Intelligence

I1. Objectives

This course is designed to learn the foundational theories of AI, enabling learners to analyze various search algorithms and their efficiency. Participants will comprehend knowledge representation techniques and reasoning mechanisms. grasp the theoretical underpinnings of machine learning algorithms, and discuss the ethical and societal implications of AI by the end of the course.

Participants will gain an overview of the foundational theories of AI, which will help them to grasp the theoretical underpinnings of machine learning algorithms, and discuss the ethical and societal implications of AI by the end of the course.

I2. Outcomes

By the end of the course, participants will know the theoretical foundation of Artificial Intelligence (AI), focusing on fundamental concepts, techniques, and algorithms. They will explore the underlying principles of AI, including search strategies, knowledge representation, reasoning, and machine learning, with an emphasis on understanding the theory behind these methods.

I2.1 Knowledge

By the end of this course, learners will be able to:

- understand AI foundations, grasping the basic principles, history, and core concepts of artificial intelligence, including its major milestones and key subfields
- employ knowledge representation and reasoning, learning how to represent information about the world in a form that a computer system can utilize to solve complex tasks, and how to reason about that information effectively
- develop planning and decision-making strategies, studying methods for creating sequences of actions to achieve specific goals and making optimal decisions in uncertain environments

- master machine learning theories, delving into the theoretical underpinnings of machine learning, including algorithms, statistical models, and the principles of learning from data
- comprehend neural networks and deep learning, understanding the structure and function of neural networks, and how deep learning models are designed and trained to recognize patterns and make predictions.
- explore the theoretical foundations of NLP, investigating the fundamental theories behind natural language processing, including syntax, semantics, and the computational techniques used to process and understand human languages.
- evaluate ethical and societal implications of AI, examining the ethical considerations, potential biases, and societal impacts of deploying AI technologies, ensuring responsible and fair use.
- stay informed on current trends and future directions, keeping up with the latest advancements, emerging trends, and future prospects in AI research and applications, staying ahead in this rapidly evolving field.

I2.2 Skills

The participants will have a basic understanding of analytical skills, problem-solving skills, programming and technical skills, as well as mathematical and statistical skills. They will also enhance their critical thinking, research and continuous learning abilities, ethical reasoning, communication skills, project management, and decision-making skills throughout the course.

I3. Course Outline

1) Introduction to AI
2) Different configurations of AI
3) Applications of AI
4) Terminologies and approaches to AI
    a. Planning and Decision Making
    b. Machine Learning Foundations
    c. Neural Networks and Deep Learning

5) AI Ethics and Society
6) Current Trends and Future Directions.

J. Big Data

J1. Objectives

This course is designed to teach the fundamental concepts and characteristics of Big Data, enabling learners to analyze different Big Data storage and processing technologies.

Participants will gain an overview of data mining and machine learning techniques to Big Data and evaluate the ethical and societal implications of Big Data technologies by the end of the course.

J2. Outcomes

By the end of the course, participants will know the foundational concepts, methodologies, and technologies for managing, processing, and analyzing vast datasets within the realm of Big Data. They will delve into the complexities, challenges, and transformative potential of Big Data applications across various domains, with the possibility of applying this knowledge specifically to the textile industry.

J2.1 Knowledge

By the end of this course, learners will be able to:

- define and explain the characteristics and challenges of Big Data, understanding the defining features of Big Data—volume, velocity, variety, veracity, and value—and the significant challenges they present in terms of storage, processing, and analysis.
- analyze and evaluate different Big Data storage and processing technologies, examining various technologies like Hadoop, Spark, and NoSQL databases, assessing their strengths and weaknesses in handling and processing large-scale data.
- apply data mining and machine learning techniques to analyze large-scale datasets, utilizing advanced analytical methods to extract patterns, insights, and predictive models from vast amounts of data, enhancing decision-making and business intelligence.

- discuss the ethical and societal implications of Big Data technologies, exploring the impact of Big Data on privacy, surveillance, and social equity, addressing ethical considerations and the need for responsible data usage.
- critically assess security and privacy concerns in Big Data applications, evaluating the risks and challenges related to data breaches, unauthorized access, and data protection in Big Data environments, proposing measures to mitigate these concerns.
- identify and discuss real-world applications of Big Data across various domains, investigating how Big Data is utilized in sectors like healthcare, finance, marketing, and logistics, showcasing its transformative potential and diverse applications.
- stay informed about current trends and future directions in Big Data research and technology, keeping abreast of the latest advancements, emerging technologies, and future prospects in the field of Big Data, ensuring a cutting-edge understanding of its evolving landscape.

J2.2 Skills

Students will develop skills in defining and analyzing Big Data characteristics, evaluating storage and processing technologies, applying data mining and machine learning techniques, discussing ethical implications, assessing security concerns, identifying real-world applications, and staying updated on current trends in Big Data.

J3. Course Outline

1) Introduction to Big Data
2) Characteristics and challenges of Big Data
3) Big Data storage technologies (e.g., Hadoop Distributed File System, NoSQL databases)
4) Big Data processing frameworks (e.g., MapReduce, Apache Spark)
5) Potential applications for Big Data
6) Big Data security and privacy considerations
7) Ethical and societal implications of Big Data
8) Future trends and directions in Big Data research.

K. Digital Product Passport

K1. Objectives

This course is designed to learn how the European Union's Digital Product Passport (DPP) initiative enhances product transparency, sustainability, and compliance in the modern economy. Participants will gain an overview of how the DPP improves traceability, durability, and certifications while leveraging 4.0 technologies like RFID and data security. Understanding these elements is crucial for businesses aiming to meet evolving regulatory demands and for consumers seeking more informed purchasing decisions.

K2. Outcomes

K2.1 Knowledge

By the end of this course, learners will be able to:

- know how the European Union's initiatives drive sustainability through the Digital Product Passport (DPP) framework
- understand the purpose and structure of the DPP, including its role in improving traceability, durability, and certifications of products
- learn about the advantages for both consumers and businesses, the challenges of implementation, and how 4.0 technologies like RFID chips and data security are integrated
- gain insights from real-world case studies, such as Renoon and Temera, showcasing different approaches and objectives for the DPP.

K2.2 Skills

The participants will have

- a basic understanding of the framework and functionality of the Digital Product Passport (DPP)

- knowledge about the benefits of DPP for traceability, durability, and certifications

- an understanding of the DPP's benefits for consumers and businesses, as well as its implementation challenges
- the ability to analyze and assess real-world DPP applications through case studies

K3. Course Outline

Introduction

1) European Union initiatives
2) Digital Product Passport (DPP)
    a. General information
    b. Traceability, durability, and certifications
    c. Benefits for consumers and businesses
    d. What form will it take?
    e. Its challenges
3) The 4.0 technologies in the DPP
    a. Data collection and transmission (include RFID Chip)
    b. Data storage and security
4) Study Cases
    a. Renoon Product Passport
    b. Temera Product Passport
    c. Two DPP, Two objectives

Conclusion

References

L. Supply Chain Management

L1. Objectives

This course is designed to learn the fundamentals of supply chain management in the textile industry, addressing specific challenges and how Industry 4.0 technologies provide innovative solutions. Participants will gain an overview of real-time data collection, data management, and secure transmission using blockchain, alongside practical examples and case studies from leading textile companies.

L2. Outcomes

L2.1 Knowledge

By the end of this course, learners will be able to:

- know the core principles of supply chain management and the unique challenges faced by the textile industry
- understand how Industry 4.0 technologies—such as real-time data collection, data analysis, and blockchain—can improve transparency, efficiency, and security within the textile supply chain, supported by real-world examples from companies like Miroglio and Benetton.

L2.2 Skills

The participants will have a basic understanding of:

- the supply chain management principles,
- the application of Industry 4.0 technologies in the textile industry
- how to analyze real-time data for better decision-making
- how blockchain technology ensures secure data transmission and assess the impact of these technologies through case studies of successful implementations.

L3. Course Outline

Introduction

Module objectives